

ECONOMIC EFFECTS OF DEEP OCEAN
MINERALS EXPLOITATION

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by

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September 1971

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Economic Effects of Deep Ocean
Minerals Exploitation

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the
NAVAL POSTGRADUATE SCHOOL
September 1971

ABSTRACT

Any international regime established to regulate the exploitation of deep ocean mineral resources will be shaped greatly by the effect this exploitation may have on the world economy. Many deep ocean mineral deposits are potentially available, but manganese nodules will probably be the first to be exploited.

This study of the economics of manganese nodules concludes that realistic production rates will severely effect the world's market price of cobalt; have significant effect on manganese and nickel prices; and cause little or no changes in the world copper market. It also shows that the royalties to be gained from an international tax or leasing system for exploitation of these nodules will not be great enough to augment significantly the economic assistance to developing nations. However, the exploitation of manganese nodules could be detrimental to the economies of specific developing countries with manganese, nickel or cobalt mining industries.

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I. INTRODUCTION

Much has been written recently about the vast potential of the oceans for supplying the increasing population of the world with vital mineral requirements demanded by our modern technological society. One effect of this publicity on the nations and governments of the world is a consensus that the mineral resources of the deep oceans should be viewed as a "common heritage of mankind" and that their exploitation should benefit all peoples rather than only those nationals of states which have the advanced technology and capital necessary to glean the wealth from these heretofore untouched deposits. This notion gained notoriety through a Maltese proposal submitted to the United Nations in the fall of 1967. As a result, the United Nations General Assembly decided to undertake an "Examination of the question of the reservation exclusively for peaceful purposes of the seabed and the ocean floor, and the subsoil thereof, underlying the high seas beyond the limit of national jurisdiction, and the use of their resources in the interests of mankind" (Ref. 1). Subsequent study and decisions by United Nations bodies established the desirability of monitoring and regulating on an international level, any future exploitation of the deep ocean seabed under a new law of the sea.

A general conference on the law of the sea is now scheduled for 1973. Meanwhile, the General Assembly is "Calling for moratorium on exploitation of seabed resources pending establishment of an international regime," and declares that "no claim to any part of that area or its resources shall be recognized" until such a regime is established (Ref. 2).

United States seabed policy accepts the principle of common heritage as evidenced by President Nixon on May 23, 1970. The President called for renouncement of all national claims over natural resources of the seabed beyond a depth of 200 meters and the establishment of an international regime to control the exploitation of seabed resources beyond this limit. He called for "the collection of substantial mineral royalties to be used for international community purposes, particularly economic assistance to developing countries," rules to prevent conflict over ocean uses, protection against pollution, assuring the integrity of investments necessary to mineral exploitation, and provisions governing the settlement of disputes (Ref. 3).

In order to create, and gain international acceptance of, a world regime for governing the use of the seabed and avoiding many potential sources of conflict, it will be necessary to determine what resources are in the deep oceans and which ones can be exploited, technologically and economically. Even when the technical exploitability of a particular mineral is ascertained, one must attempt to

predict the effects of its exploitation on the world market, based on projected demands and production rates. With this information in hand, an equitable scheme for establishing rules and controls over exploitation and for distributing mineral royalties within the international community may be designed.

II. PROSPECTIVE WORLD AGGREGATE MINERAL DEMAND

A. POPULATION TRENDS

In 1968, the world population was estimated to be 3,509,100,000. Over 2.5 billion or about 72.5% of this population resided in developing countries, defined as: all the states in Latin America, East Asia and the Pacific less Japan and Australia, South Asia and the Indian Ocean, the Near East, Africa less the Republic of South Africa, Albania, Bulgaria, Greece, Portugal, Spain, Turkey and Yugoslavia (Ref. 4). Population projections for the year 2000 are 6,389,000,000 for the world, with 4,777,000,000 or about 74.8% belonging to the less developed countries. By the year 2020, the world's population is expected to increase to 9,025,000,000 while the share of developing countries will be an even greater percentage (Ref. 5). On the basis of these population statistics alone, one could expect the world demand for minerals to increase 174% by the year 2000 and 257% by 2020. It is also reasonable to assume that changes in the values and tastes of the world's people will require higher standards of living, causing greater demands for raw materials.

B. GROSS NATIONAL PRODUCT

Predictions of the world aggregate of gross national product (GNP) are another indication of future demands.

In 1968, the total GNP for the world was \$2,685,006,000,000. Developing countries accounted for \$450,066,000,000 of this or only 16.8% of the world total (Ref. 4). Gross national product predictions for the world of 2000 total \$10,848,000,000,000 with the developing nations producing \$1,589,000,000,000 or 14.6% of the total. By the year 2020 the world's GNP figures are expected to reach the neighborhood of \$28,711,000,000,000 (Ref. 5). With these figures, future per capita GNP can be estimated and used as an indication of mineral demands:

TABLE I
PER CAPITA GNP PREDICTION

	1968	2000	% Increase 1968 - 2000	% Increase 1968 - 2000
World Total	\$ 865	\$1,690	195	\$3,182
Developed Nations	2,312	5,770	249	
Developing Nations	177	321	182	

If future mineral demands were assumed to increase proportionally to the world's GNP, they would be 407% greater than the 1968 demand by the year 2000 and 1069% higher in 2020. A substantial reduction in the above projections, however, must be calculated because of the disparity in per capita GNP between people in developed and developing nations and the de-escalating rate

of industrialization in developed countries owing to a larger portion of income being directed towards education, services and leisure.

Other considerations, such as the substitution for current mineral uses by synthetics, increased dependence on recycling scrap materials as a source of mineral supply, and the possibilities of war or famine would greatly effect future demands for raw materials. These conditions are impossible to predict with any precision. Ignoring them and assuming that demand will increase at about 75% of the GNP rate, a reasonable projection for the year 2000 would be 300% of 1968's demand and by 2020 some 700% more than 1968.

III. MINERAL RESOURCES

World mineral resources are defined as both known and undiscovered minerals of prospective value. Resources encompass the total world supply of minerals. Mineral reserves are those deposits that are economically recoverable using today's technology and at today's prices (Ref. 6). Resources can become reserves with an increase in geologic knowledge or discovery of new deposits. Reserves will increase as a result of better technological abilities, enabling lower grade or more remote deposits to enter into that category. Also, either an increase in market price of a mineral or a decrease in mining or production costs will have the effect of increasing reserves. Reserves may also be broken down into (1) proven reserves; (2) indicated reserves for which locations are known but sizes are not; (3) inferred reserves for which neither size nor exact location have been determined; (4) latent reserves which are not yet commercial and (5) alternative-resource reserves from which usable substitute substances may be obtained, if and when necessary (Ref. 7).

The adequacy of the earth's mineral supply varies for different commodities. Iron and aluminum supplies, for example, appear to be sufficient for several centuries. Silver and mercury, on the other hand, are already scarce. Their prices are rising and substitutes are being sought

(Ref. 8). Most other mineral commodities lie between these two extremes. Vast new reserves must become available if the greater part of mineral supplies are to keep abreast of the anticipated increases in world demand. Need is especially critical for new reserves of fossil fuels.

Historically, the aggregate of mineral supplies has kept up with increased demand. Mineral prices over the long term have not shown marked increase relative to other economic indicators. This stability has resulted from successive improvements in technology, which have decreased need for capital and labor per unit of mineral output. We cannot count on this phenomena to continue indefinitely into the future, when the amount of mineral consumption will be many times greater than it has been in the past.

One shortcoming of any analysis on this subject is that data on world mineral reserves are poor. Estimates are conservative and tend to be understated. Data on resources are worse. Because of a lack of definitions, estimates are misleading and, for some underdeveloped nations, information may be entirely absent. Under such conditions, it is inappropriate to attempt estimating world mineral supplies. We can only obtain broad indications as to further possibilities (Ref. 9).

It is unargued that deep ocean mineral resources will help to satisfy future world demand. These minerals will increase the world's stock of capital, but they are only one potential addition to mineral reserves and will compete with terrestrial reserves, both present and future (Ref. 6).

IV. PROSPECTIVE DEEP OCEAN MINERAL RESERVES

A. PETROLEUM

Although offshore oilwells have been operational only since 1948, the technology for both offshore exploration and production is now well developed with offshore petroleum accounting for 18% of total world production in 1970 (Ref. 10). Plans for new wells in water as deep as 1,000 feet have been announced (Ref. 11). Movement into even deeper water is inevitable, with only minor increases in production costs. Regions of thick sediments with structural and stratigraphic traps will provide the best prospecting conditions in the deep oceans as they do on land and the continental shelves.

1. Semi-Enclosed Seas

Semi-enclosed seas are strong prospects for deep ocean petroleum reserves. Admittedly, many of these seas are shallow and belong to the continental shelf of coastal states, but others are of great depth while having a crustal structure similar to that of the continents. For example, the Gulf of Mexico has sediment thicknesses of 5 to 20 kilometers; numerous salt diapirs have been located in this region, indicative of petroleum reserves (Ref. 12). The JOIDES deep sea drilling project recovered oil in cores from cap rock in a water depth of 11,720 feet in the Sigsbee Deep (Ref. 13). Continued exploration in semi-enclosed seas is needed in order to better assess their full potential.

2. Continental Rises and Slopes

Continental rises and slopes sometimes have sediment thicknesses of 10 kilometers or more. Although these thicknesses are not everywhere present, they can normally be found off the deltas of major rivers. Seismic sections in these areas indicate that both structural and stratigraphic traps are present (Ref. 14). The volume of sediment on continental rises and slopes is probably larger than that on the continental shelves and could, therefore, be a substantial source of petroleum in the future.

3. Deep Ocean Basins

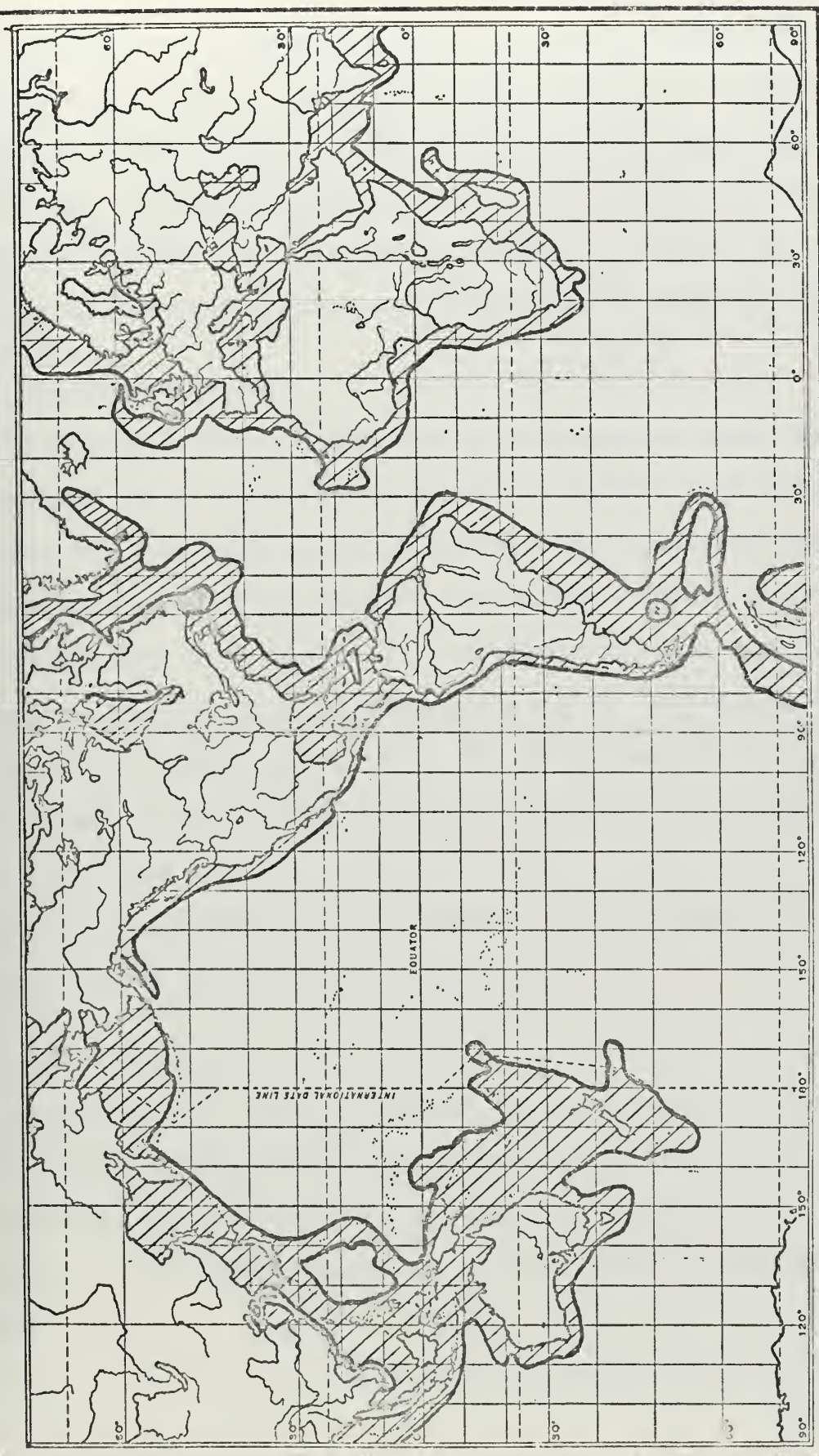
The deep ocean basins themselves are a relatively poor prospect for petroleum deposits as their sediment thickness is usually on the order of 0.5 to 2.0 kilometers and little evidence of tectonic folding or distortion is present (Ref. 14).

The potential significance of the deep ocean as a source for petroleum deposits will be established within the next two decades when rising demands make these less accessible petroleum deposits competitive with existing reserves under the land and continental shelves. Meanwhile, lack of geologic knowledge and higher drilling costs in deeper water make continued exploitation of land and continental shelf petroleum more profitable.

B. PHOSPHORITE

Phosphorite nodules have been dredged at depths up to 11,400 feet at the base of the continental slope. However,

Figure 1 Potential Offshore Petroleum Regions (Ref. 15)



the nodules were probably carried to these depths by slumping or turbidity currents from larger deposits resting under shallower water on the continental shelves (Ref. 16). Since any propensity for mining these nodules would be directed toward the continental shelves, phosphorite deposits can be eliminated as prospective deep ocean mineral reserves.

C. CALCAREOUS OozES

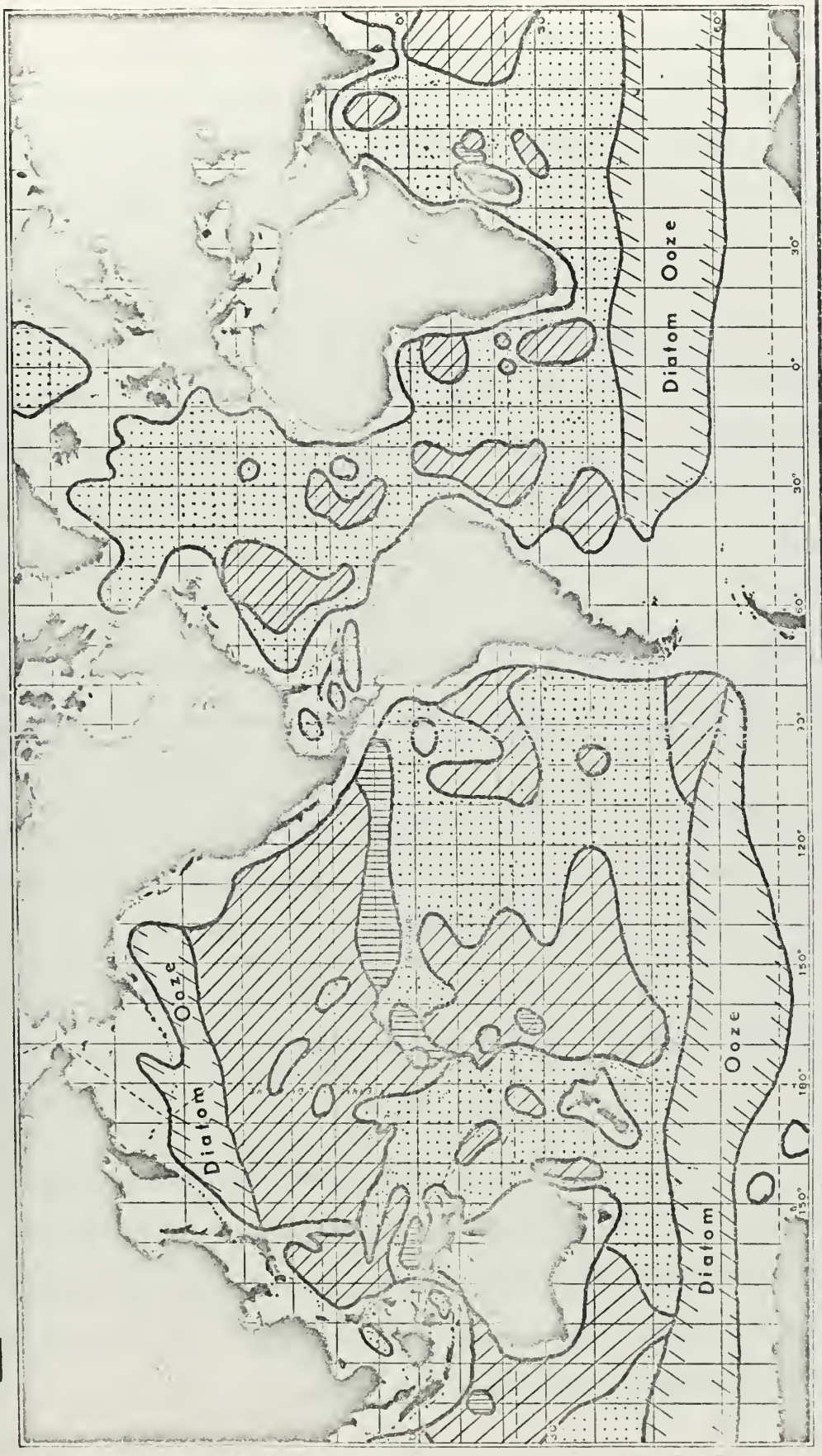
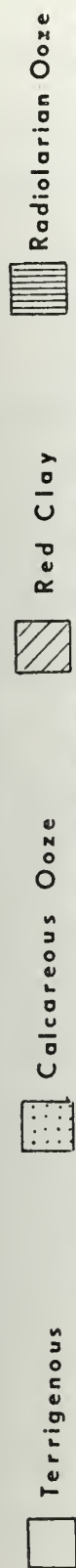
Calcareous ooze, particularly globogerina ooze, has been mentioned as an alternative source of cement rock because it has the required chemical content and necessary physical characteristics; fine grained and unconsolidated with a large surface area (Ref. 17). Globogerina ooze covers approximately 35% of the ocean floor with an average thickness of 400 meters (Ref. 17). It is a substantial resource, but cement rock in various forms is plentiful on land except for shortages in certain local areas. In any event, the low commercial value of calcareous ooze precludes its economic exploitation from the deep ocean.

D. DIATOM OOZE

Diatom ooze, covering almost 9% of the ocean floor with an average thickness of 200 meters, could be used as a substitute for diatomite. The assay of diatom ooze is favorable for this purpose as are its physical properties (Ref. 17).

It is not likely, however, that diatom ooze will become economically competitive with diatomite, because the current

Figure 2 Ocean Sediment Types (Ref. 18)



value of diatomite is less than \$3.00 per ton at the mine site. Diatomite also has other substitutes, such as perlite and vermiculite, which are already replacing it for some uses (Ref. 19).

E. RED CLAY DEPOSITS

Red clay, covering about 28% of the ocean floor with an average thickness of 200 meters, is basically composed of hydrated aluminum silicates. Assays of up to 25% aluminum oxide make it comparable to some land deposits of aluminum ores (Ref. 17). However, land deposits are extensive and generally more valuable.

Using red clay as a construction material is also a possibility, but available terrestrial clay deposits are far more economic.

Red clay is usually contaminated with an average of one to two percent manganese grains. These grains are also associated with minute quantities of copper, nickel and cobalt. Because of the low concentration of these grains in red clay, their exploitation would not be economically desirable (Ref. 17).

F. RED SEA METALIFEROUS MUDS

Heavy metal deposits were recently found in the Red Sea in conjunction with the mid-ocean ridge system extending into that area. Deposit depths are from 2000 to 2170 meters and cover a total area of approximately 75 square kilometers (Ref. 20).

Exploration to date is not extensive. Only eighty cores have been taken in the deposit region to a maximum depth of 10 meters. Six facies have been identified with varying metal assays. A metaliferrous sulfide facie, penetrated by only four cores thus far, appears to have the richest assay (Ref. 21). Typical average assay values for the top 10 meters of the largest deposit, Atlantis II Deep, are depicted in Table II. Figures 3 through 5 show the location, bathymetry and cross section description of the deposits.

A considerable amount of new technology is needed before exploitation of these metaliferrous muds becomes feasible. Mining technologies would have to be achieved for selective dredging of the best facies, de-watering the extracted muds and disposing of waste material. Even when mined material can be taken to a processing site, new techniques must be found to extract the metals from this unusual ore (Ref. 22).

As a result of intensive exploration efforts and continued technological research, the Red Sea metaliferrous muds will undoubtedly become a new reserve for metals of world-wide importance. The economic value of these deposits cannot be determined with any accuracy until mining and processing techniques are further researched and the costs and benefits evaluated with more certainty. Progress will take time. Although mining rights have been applied for by several groups, and others have indicated an interest, production should not be expected in the near future (Ref. 24).

TABLE II

GROSS VALUE OF METALS IN UPPER 10m OF THE ATLANTIS II DEEP (Ref. 23)

Metal prices from Engineering and Mining Journal, December 1967.

Value per ton brine-free material = \$30; per m³ in-place sediment = \$5.2.

Price (dollars per ton)	"Goethite"		"Fe Silicate"		"Sulfide"		Totals		Value \$×10 ⁷
	Tons	Value ¹ \$×10 ⁷	Tons	Value \$×10 ⁷	Tons	Value \$×10 ⁷	Averaged Assay (%)	Tons	
Fe -	143 ×10 ⁵	-	55 ×10 ⁵	-	45 ×10 ⁵	-	29	243 ×10 ⁵	-
Zn 300	3.3×10 ⁵	9.9	8.4×10 ⁵	25.2	16.9×10 ⁵	50.7	3.4	29 ×10 ⁵	86
Cu 1,200	2.1×10 ⁵	25.2	1.3×10 ⁵	15.6	7.2×10 ⁵	85.3	1.3	10.6×10 ⁵	127
Pb 300	0.3×10 ⁵	0.9	0.2×10 ⁵	0.6	0.3×10 ⁵	0.9	0.1	0.8×10 ⁵	2
Ag 62,400	12 ×10 ²	7.5	11.9×10 ²	7.4	21 ×10 ²	13.1	0.0054	45 ×10 ²	28
Au 1.2 10 ⁶	12	1.3	11.9	1.4	21	2.3	0.5 ppm	45	5
Totals		44.8		50.2		152.3			248

¹The value of the iron content is considered to be negligible, because it could not compete with current higher grade reserves for which the metallurgy has been perfected.

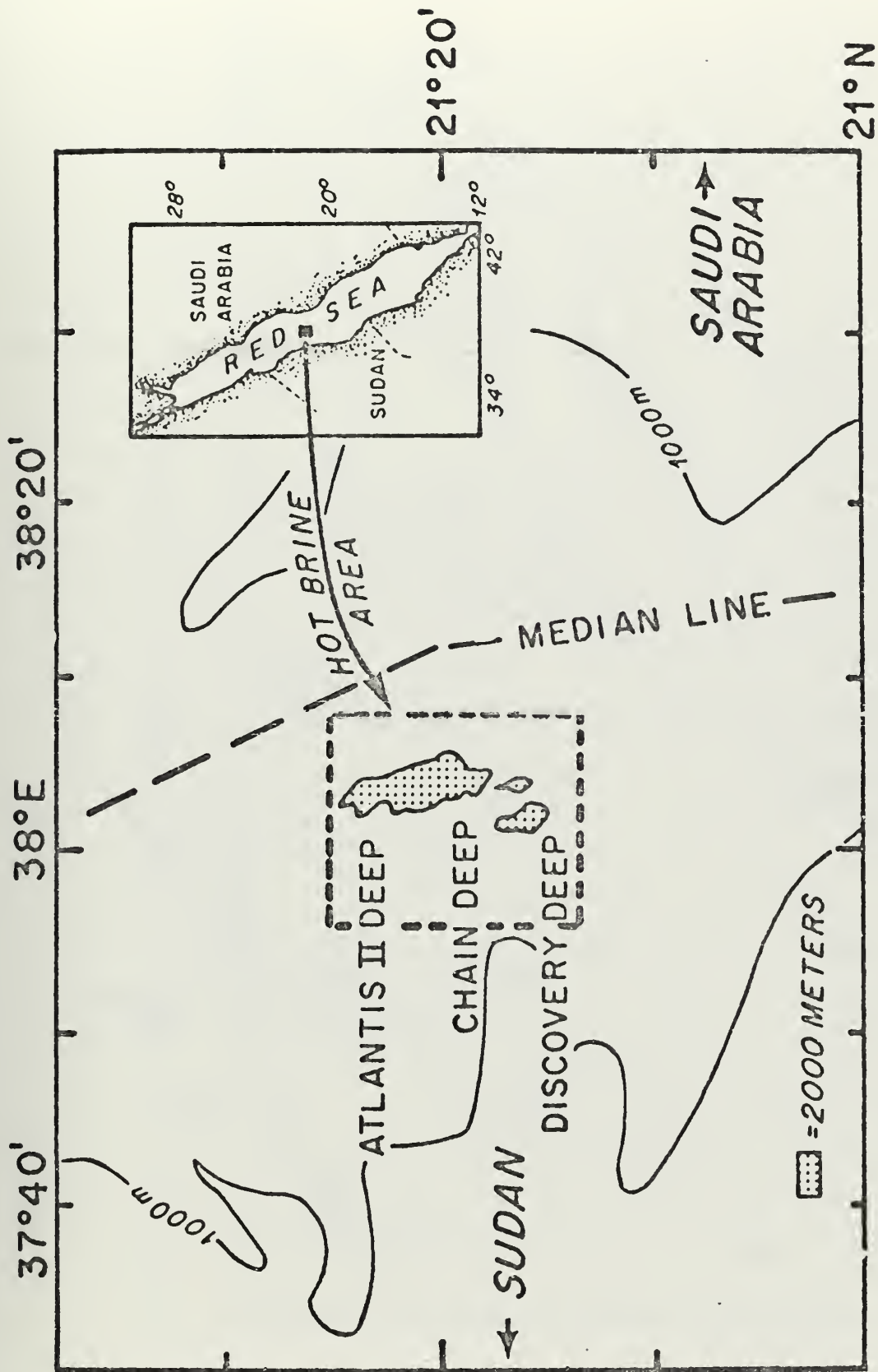
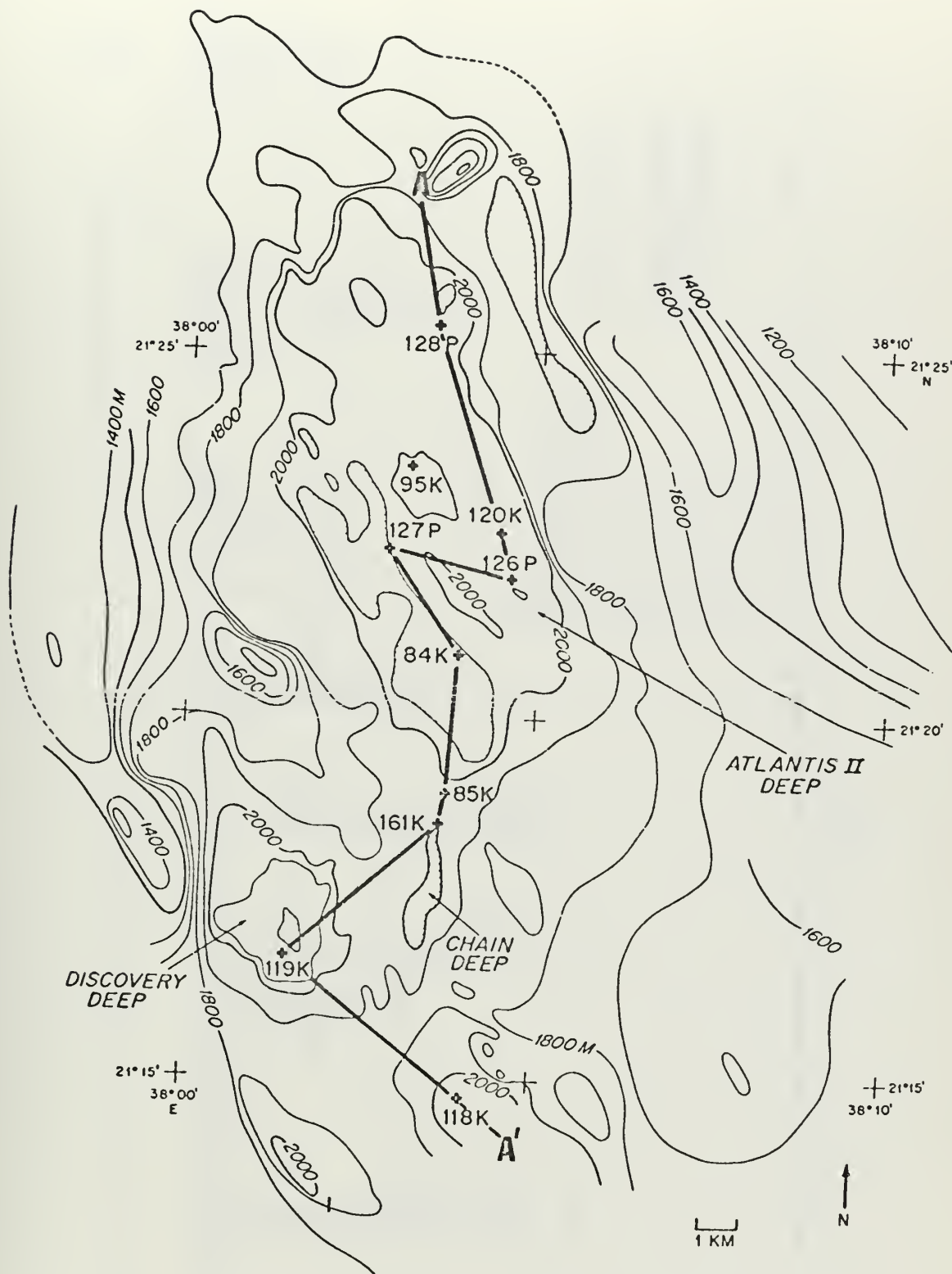
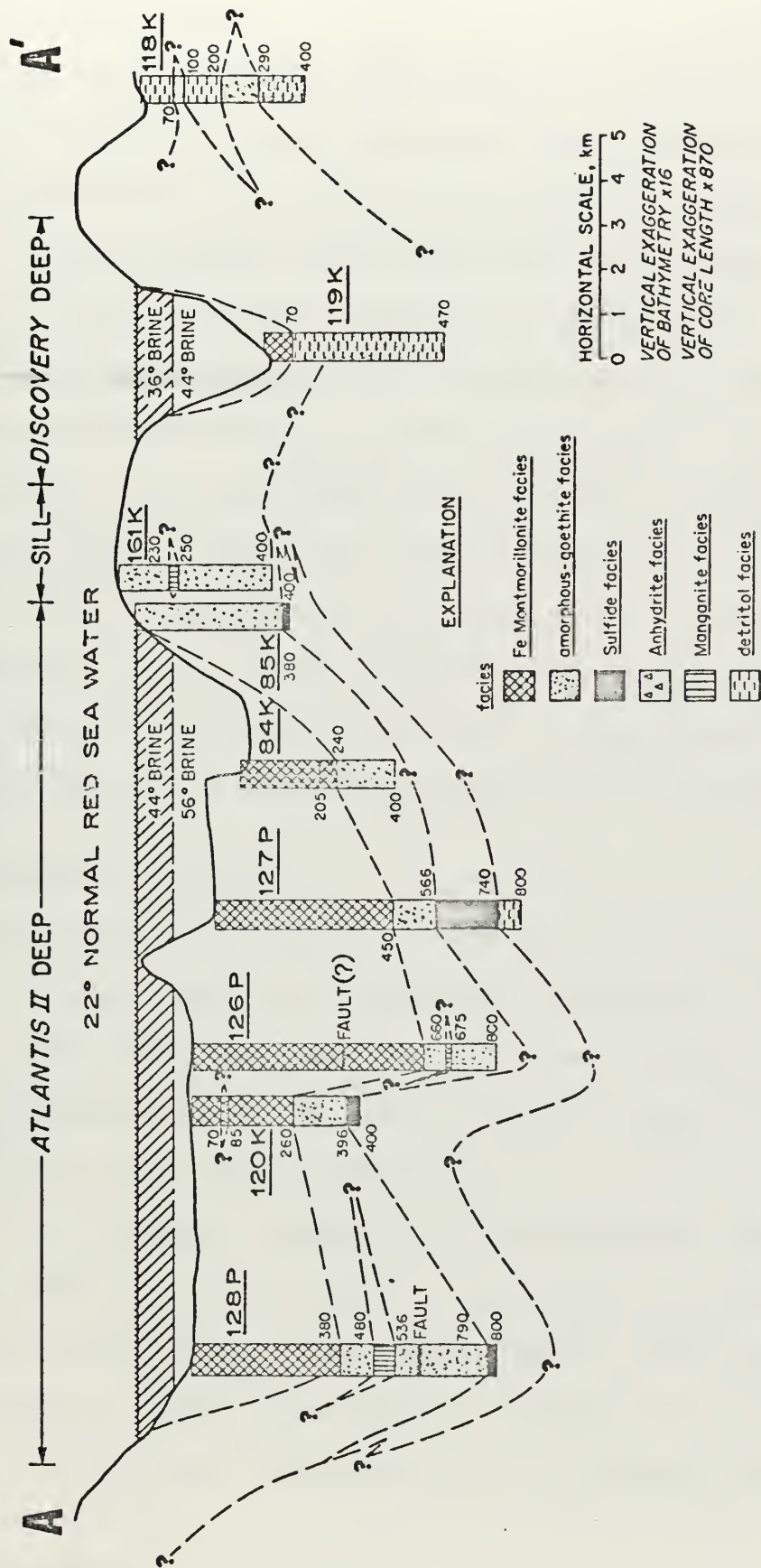


Figure 3 Bathymetric map of brine area. (Ref. 23)



Bathymetry of brine deeps and location of analyzed cores.

Figure 4 (Ref. 21)



Generalized cross section through Atlantis II and Discovery Deep. Small numbers beside cores refer to depth in cm. (REF. 21.)

Figure 5

G. MID-OCEAN RIDGES

Since the conditions under which the Red Sea metal deposits were formed are associated with the mid-ocean ridge system (Ref. 25), it is reasonable to assume that similar conditions may exist along the approximately 40,000 miles of mid-ocean ridges throughout the world.² As yet, no similar deposits have been located, but the possibility of their existence cannot be ruled out until an extensive exploration of the mid-ocean ridge system is undertaken.

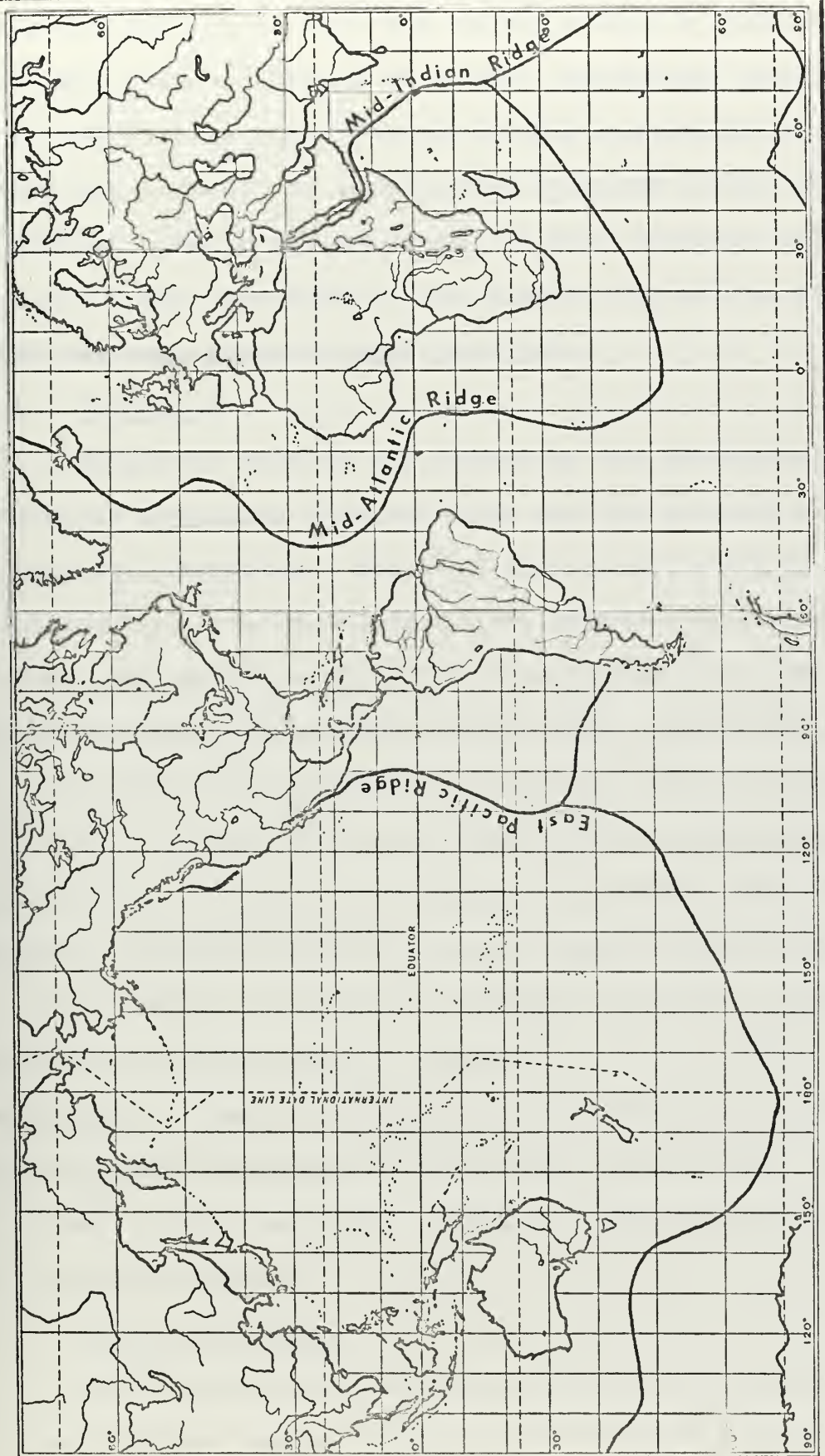
Additionally, there are potentialities for copper, concentrated by metamorphism, to exist along the mid-ocean ridge system, while similar deposits of chromite or platinum may be found in peridotite (Ref. 26). Such possibilities are speculative; no evidence confirms their existence.

H. MANGANESE NODULES

The presence of manganese nodules on the deep ocean floor is known since the "Challenger Expedition" of 1873-1876. The nodules vary in size from small grains to one of 1,770 pounds recovered east of the Philippine Islands. They can be found almost anywhere in the deep oceans (Ref. 27). Tonnage estimates for the Pacific Ocean alone reach 1.66 trillion tons (Ref. 28). Nodule density varies over the ocean bottom. Reported ranges on the Pacific Ocean floor are from less than 0.1 pounds per square foot to over 7 pounds per square foot, and standard deviations

²See Figure 6.

Figure 6 Mid-Ocean Ridge System



of 1 pound per square foot are common within a locality (Ref. 28). Concentrations of nickel, manganese, copper, cobalt and possibly other metals having commercial exploitability are locked into complicated hydrated oxides within the nodules. While the existence of this treasure has been known since the late 1800's, the feasibility of its exploitation has only recently been realized.

1. Formation

Manganese nodules are formed by the precipitation of metallic compounds from solution and the process of particle agglomeration. The mechanism is believed to be one of precipitation of electrically charged, hydrated iron and manganese oxide particles from saturated sea water. These charged particles then attract other metal ions from the water and attach themselves to objects such as sharks' teeth or rock fragments on the ocean floor to form manganese nodule nuclei. A continuous supply of charged colloidal particles allows the nuclei to grow, layer by layer, until they are buried in sediment at which time growth ceases. Deep ocean currents play an important role in nodule development as they are responsible for bringing colloidal materials into the areas of deposition and sweeping sediment from or over the nodule surfaces, enhancing or retarding accretion (Ref. 17).

2. Grade Variations

Metal assays for manganese nodules vary from location to location, making deposits in certain areas more

favorable than others. In order to determine thoroughly the distribution of nodule types, extensive sampling will be required. With the recent efforts to exploit deposits of manganese nodules, faster and less expensive sampling techniques are being developed (Ref. 28). Better knowledge of nodule formation will also help in predicting nodule grades, as variations are believed to result from differences in initial formation processes, subsequent physical and chemical erosion, sea water element concentrations, hydrostatic pressures, temperatures and, possibly, bacteriological activity (Ref. 17).

With respect to economic exploitability, nodules in the Pacific Ocean are generally of higher grade than those of the Atlantic or Indian Oceans. Atlantic nodules contain less manganese, copper, cobalt, molybdenum and titanium, but are usually less variable in composition than Pacific nodules. In the Indian Ocean, the nodules show smaller average assays of manganese, nickel, copper and cobalt--the four primary exploitable constituents.

3. Exploitation Requirements

Exploitation of manganese nodules will require identification of mine sites that provide the best commercial nodules in adequate abundance. The proximity of a mine site to prospective markets will also be a consideration in any sites' selection. Each specific mine site will require intensive quantitative and qualitative sampling, exploration of bottom characteristics and searches for

bottom obstructions. Currents, salinities, temperatures, sea conditions and other meteorological or oceanographic information must also be known (Ref. 29).

Numerous mining techniques have been proposed (Refs. 30 and 31) and at least two have been successfully tested. One of these, a hydrolic suction dredging system, was tested in 2,500 feet of water on the Blake Plateau off the coast of Florida and Georgia in July, 1970, by an American firm (Ref. 32). The other system, drastically different, was tested in September, 1970, near Tahiti in 3,760 meters of water from a Japanese ship; it consisted of a mechanical "continuous line bucket" dredge (Ref. 33). Other systems are being built, but information on these has not been published (Ref. 34).

Once raised to the sea surface, transportation of mined manganese nodules to shore can be accomplished by the mining vessel itself, by ore carriers onto which the ore is transferred at sea (Ref. 29), or by ocean-going tugs pulling barges. Transport via the mining vessel would require the smallest capital investment, but would cause a loss in mining time and involve raising or disconnecting the mining rig each time the vessel is filled to capacity.

Several methods have been proposed for processing nodules, once they have been taken ashore (Refs. 35 and 36). The constituent metals are in the form of oxides instead of sulfides, as normally found in terrestrial ores. This circumstance requires a completely new chemical engineering

approach at refining plants. Deepsea Ventures, one of the companies doing research in this area, has a pilot plant in operation which is capable of processing one ton of nodules per day. Tentative plans are to enlarge this model until a plant capacity of 3,000 tons-per-day will be reached by 1975 or 1976 (Ref. 37). This plant will eventually be capable of processing the 1,000,000 tons-per-year that Deepsea Ventures envisages mining (Ref. 31).

V. EFFECTS OF MANGANESE NODULE EXPLOITATION

Manganese nodules, it appears, will be the first deep ocean mineral resource to be exploited commercially. This event will provide the initial test for any international regime formed to regulate the exploitation of deep ocean minerals. The structure of such a regime must necessarily be geared, in the first instance, to the exploitation of these nodules. Conflicts of interest among those concerned with mining and those advancing other commercial, military, or broader public interests will certainly come before the international regime for anticipatory regulations or contentious settlement. Bases for the settlement of disputes among mining companies and public authorities over rights to sea floor deposits will need to be established. Thus, the exploitation of manganese nodules can be expected to shape a new law of the sea.

A. VALUE OF METALS IN NODULE GRADES

Concern has been expressed over the effect large scale mining of manganese nodules will have on the prices of constituent metals. Because of the disparity between the ratio of constituent metals in the nodules and the ratio of their world demands, this concern is warranted. With many different grades of nodules available, the extent of the disparity will be dependent on the type of nodule mined.

The Pacific Ocean, having the best overall commercial grades of nodules, can be divided into areas of high manganese, high nickel and copper, and high cobalt content, as depicted by Figure 7.³ Table III shows constituent metal contents for average-assays of these nodule types, plus the composition of nodules from the proposed Deepsea Ventures' mine site. Values of metal yield per ton of nodules at 1971 prices are also shown in Table III, using a 98% processing yield figure claimed by Deepsea Ventures (Ref. 38). It can be seen that nodules with high copper and nickel or high cobalt content are the most lucrative commercially at current market prices. High manganese content nodules, on the other hand, are typically poor in the other metals and have the lowest commercial value of the types shown.

Metal yields for various grades of nodule deposits are shown in Tables I-IV, Appendix A, using increments of 1,000,000 tons of mined nodules per year as proposed by Deepsea Ventures and assuming a 98% processing yield. Figures for the world production of constituent metals in 1969 and projected low and high estimates of world demand in 1985 and the year 2000 are depicted by Table IV and Figures 8-11. These projected figures estimate an approximate 300% increase in world mineral demand by the year 2000 and are consistent with the demands noted earlier in this paper.

³Of geological interest is the high cobalt content area which follows the shallower regions of the Pacific rise system, including the Emperor Seamount Chain, the Hawaiian Ridge and the Line, Society and Cook Islands.

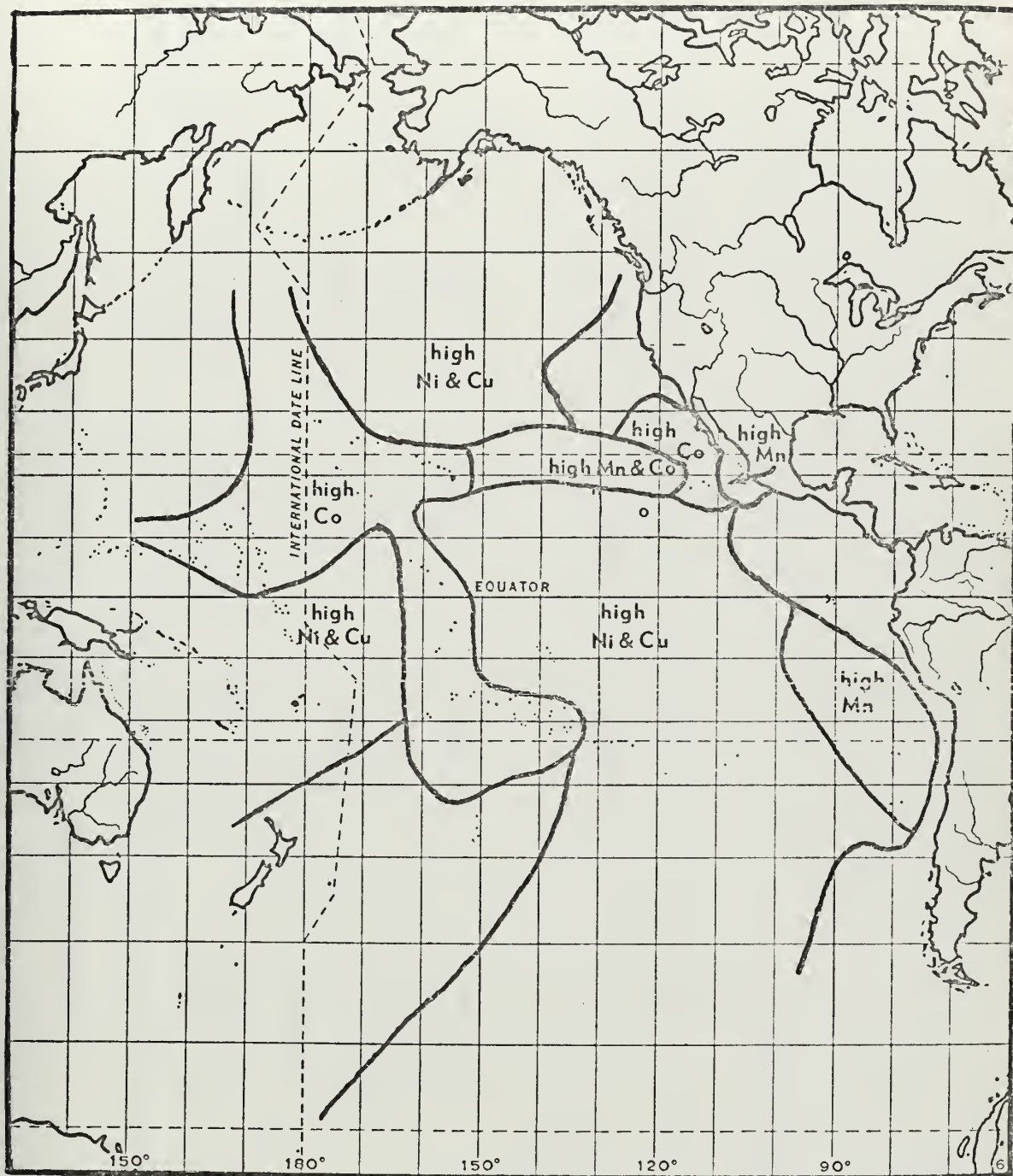


Figure 7 Pacific Nodule Types (Ref. 17)

TABLE III

METAL CONTENT AND VALUE OF NODULE TYPES

Metal	1971 Market Price*	High Mn Content Nodules**	High Ni and Cu Content Nodules**	High Co Content Nodules**	Deepsea Ventures' Mine Site Nodules***
Manganese Ore ⁵	\$.03 per lb.	49.80%	33.30%	28.50%	26.00%
Nickel	1.28 per lb.	0.26	1.52	0.66	1.26
Copper	.52 per lb.	0.14	1.13	0.21	1.00
Cobalt	2.20 per lb.	0.055	0.39	1.20	0.24
Value of Metal Yield Per Ton of Nodules at 1971 Prices		\$39.72	\$86.12	\$87.18	\$67.43

⁵Based on 46% Mn Ore.

* (Ref. 39).

** (Ref. 17).

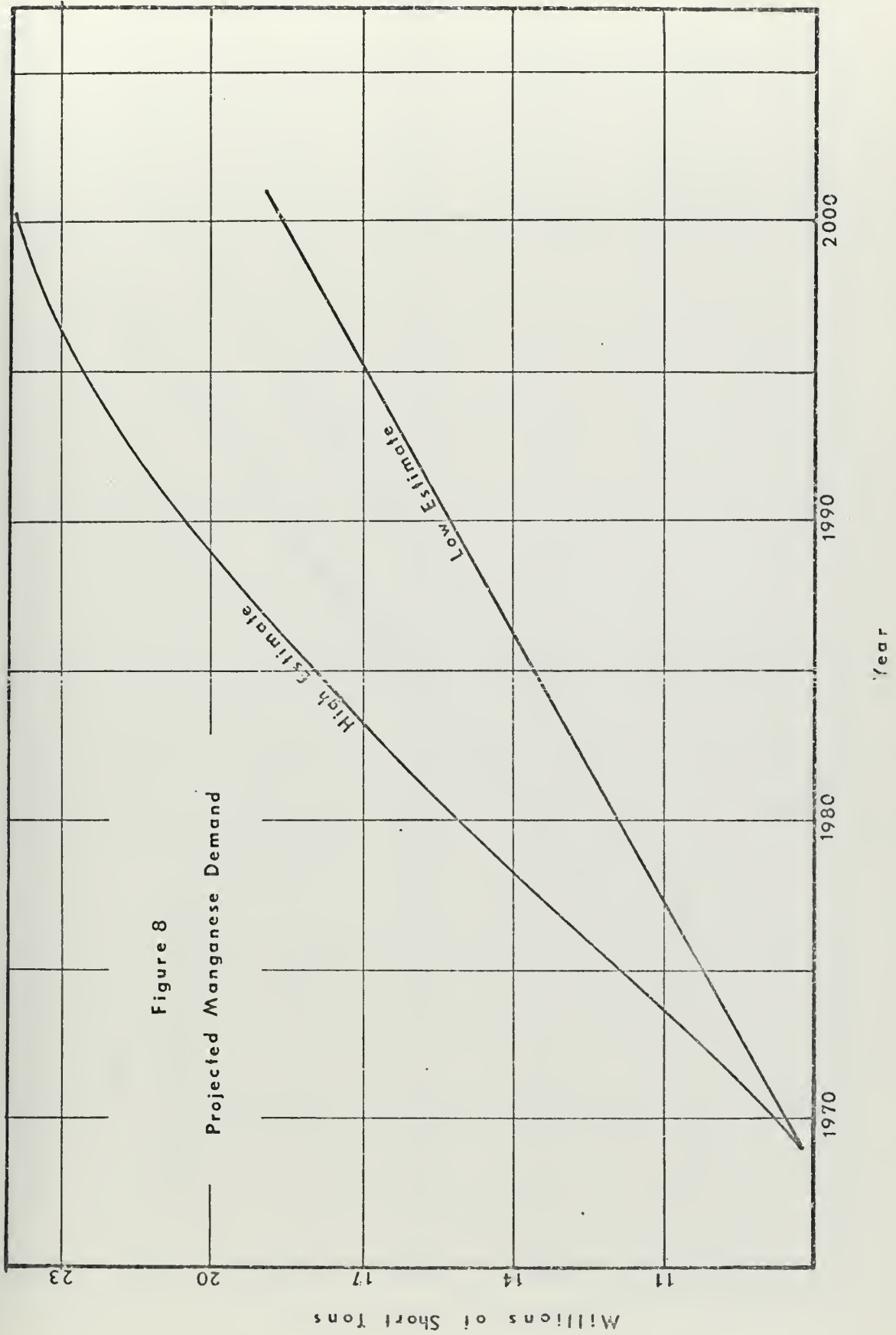
*** (Ref. 37).

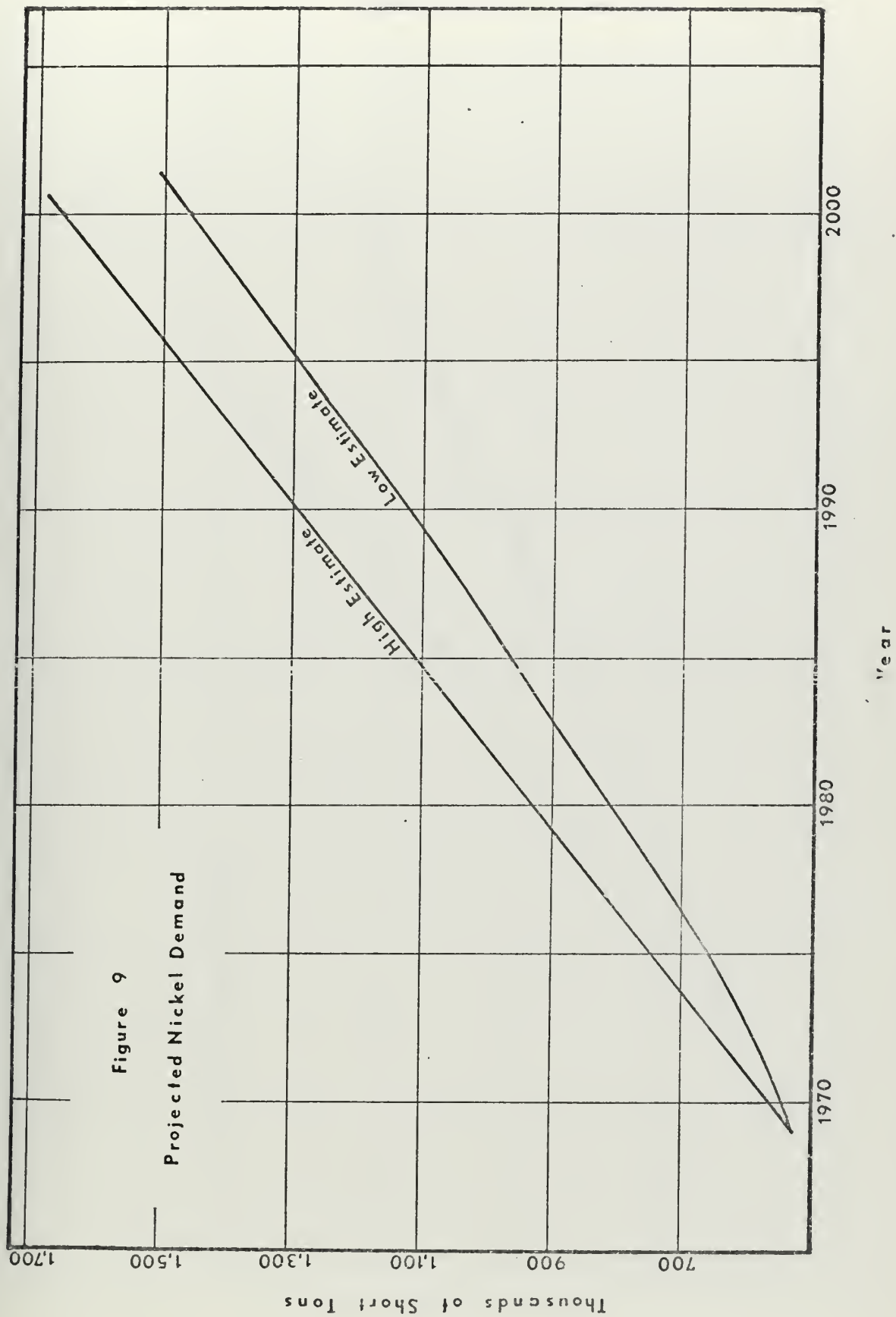
TABLE IV
PROJECTED CONSTITUENT METAL DEMAND
(Short Tons)

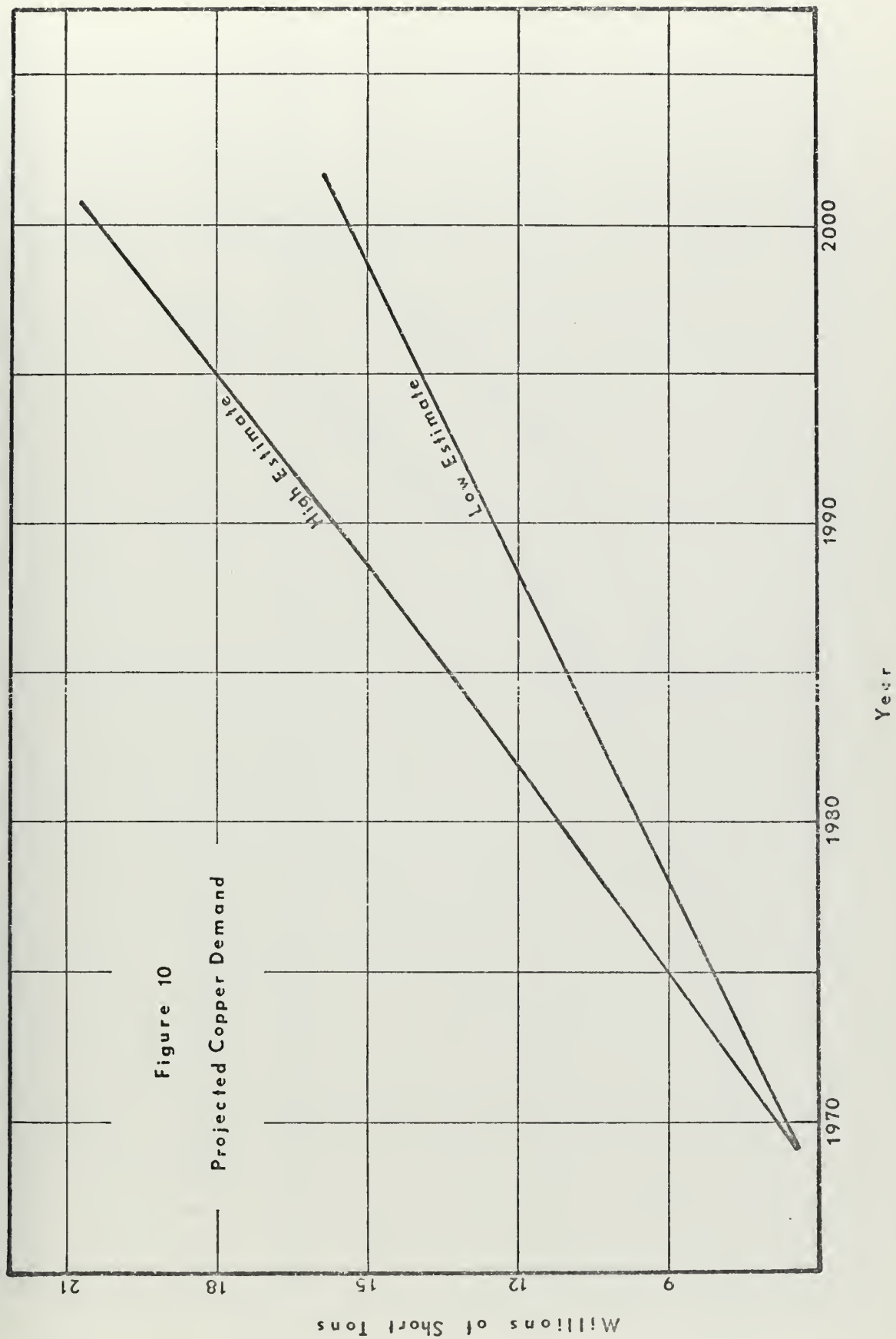
	1969* Production	1985**		2000**	
		Low Estimate	High Estimate	Low Estimate	High Estimate
Manganese Ore	8,160,000	13,700,000	17,950,000	18,265,000	23,900,000
Nickel	530,495	960,000	1,018,000	1,464,000	1,665,000
Copper	6,612,276	11,200,000	13,500,000	15,700,000	20,600,000
Cobalt	22,296	25,650	28,250	40,550	48,850

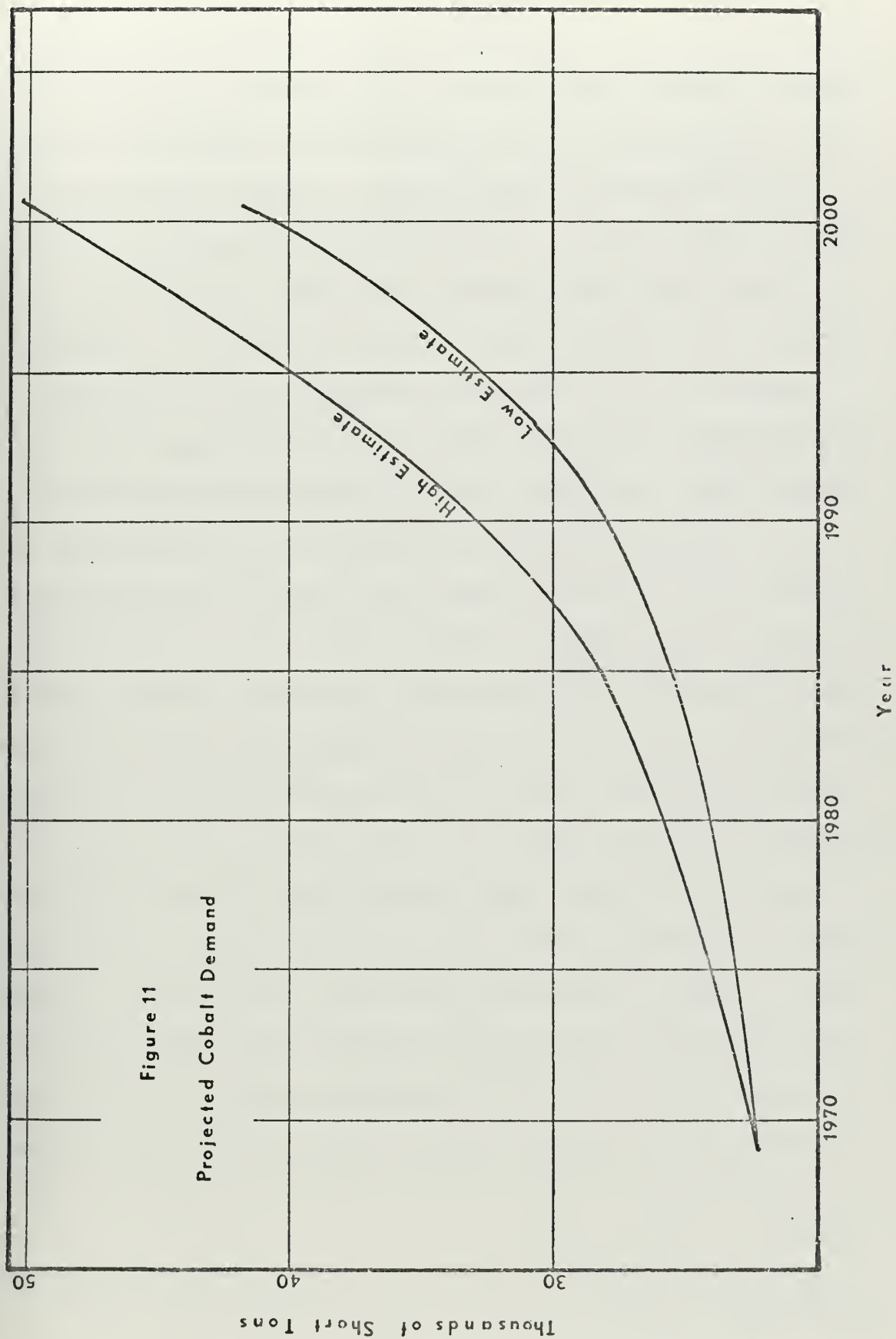
* (Ref. 40) .

** (Ref. 41) .





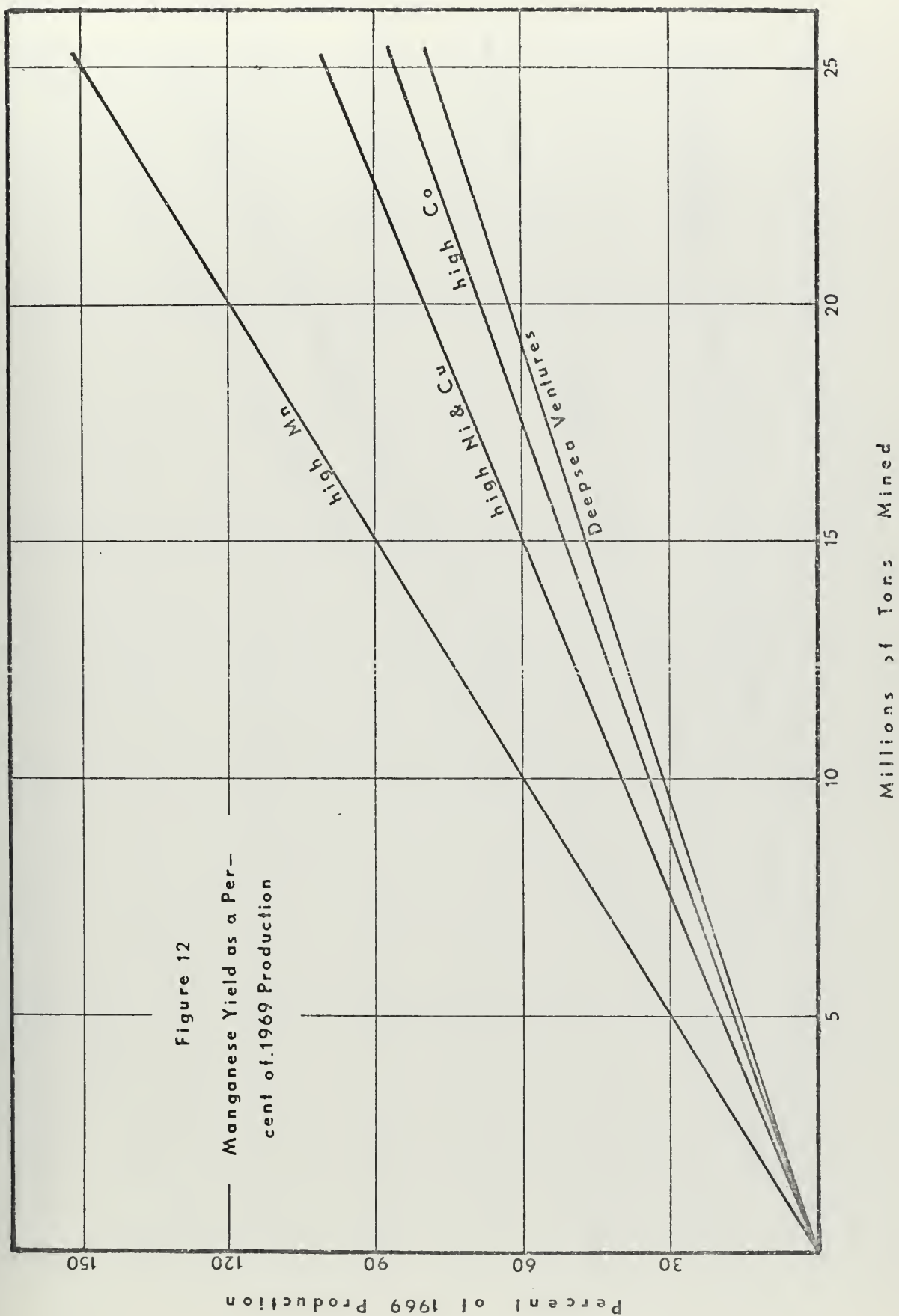


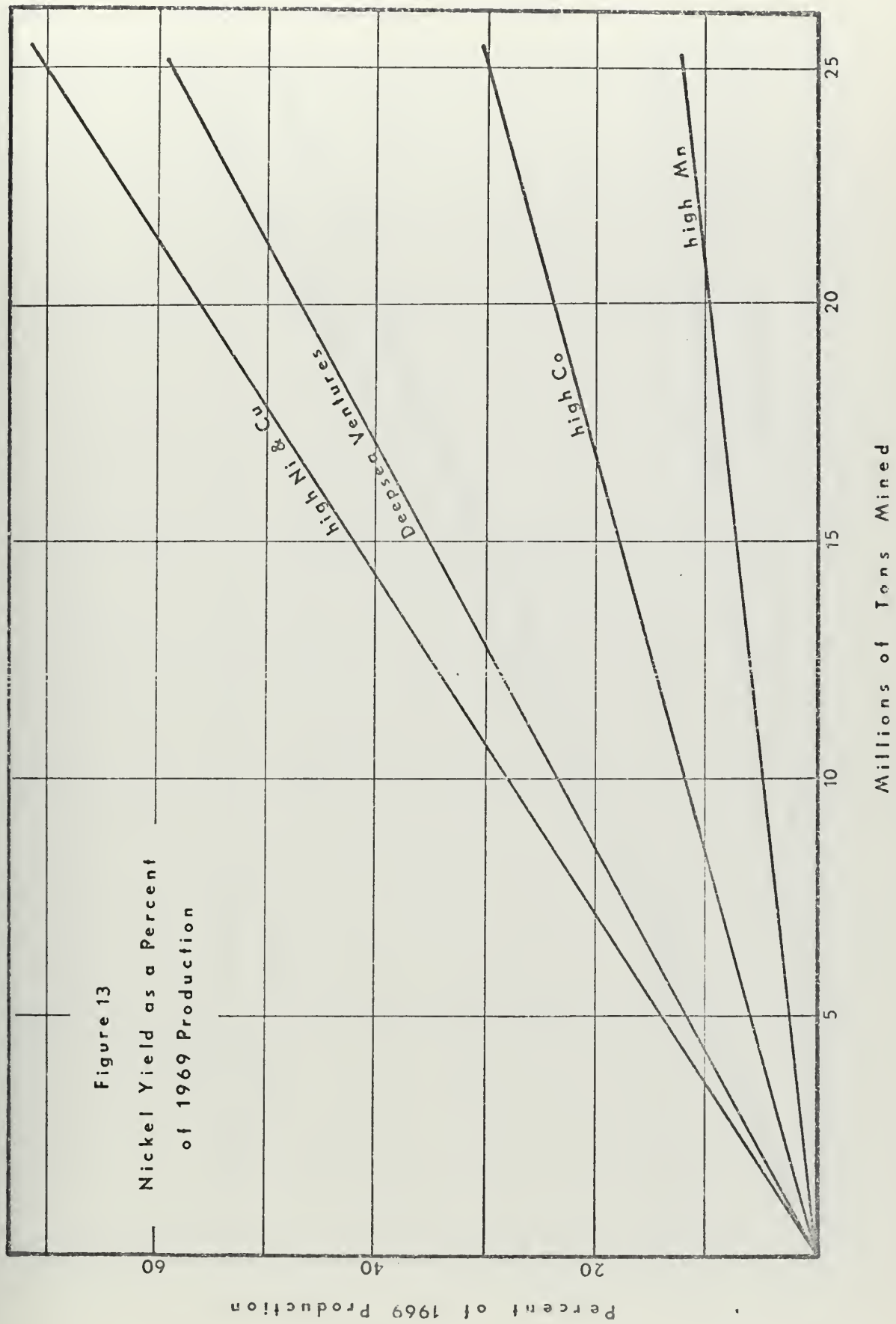


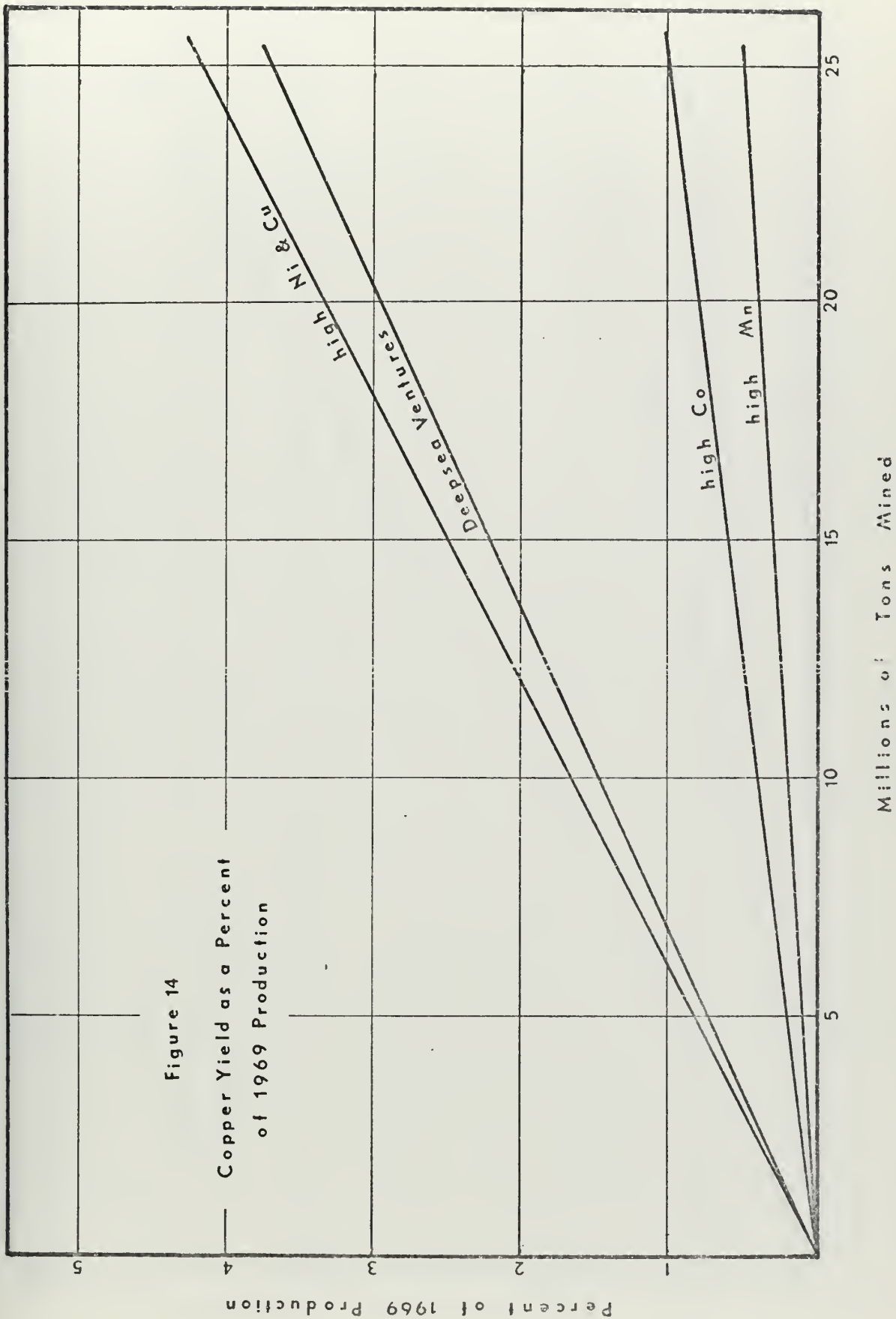
B. EFFECTS ON CURRENT METAL MARKETS

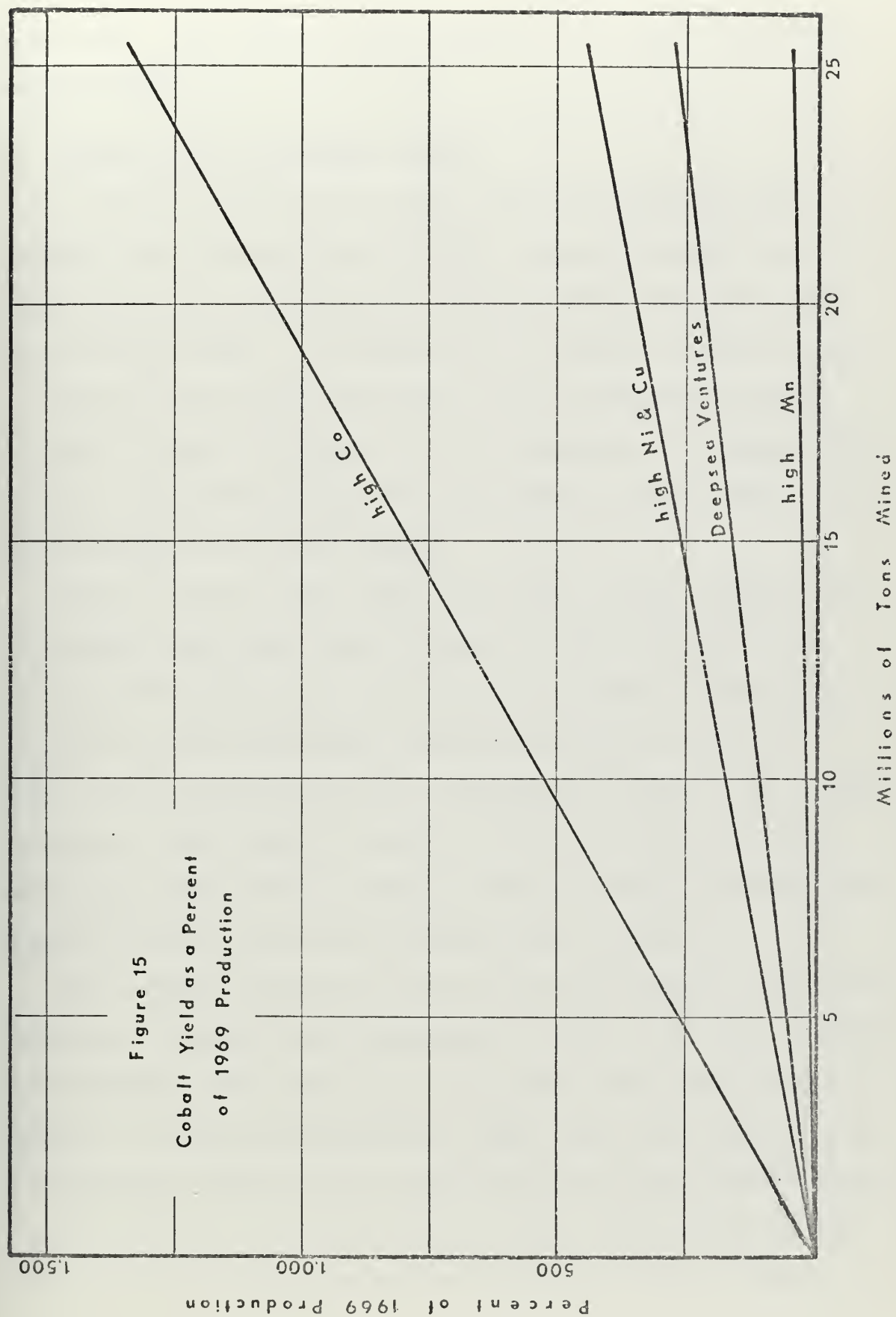
In order to determine the effect that extensive exploitation of manganese nodules may have on future prices of the constituent metals, one must compare expected metal yields with actual world production. Tables V-VIII, Appendix A, and Figures 12-15 show anticipated yields from increments of 1,000,000 tons of mined nodules as a percent of reported 1969 world metal production. It is obvious from this comparison that the mining of 1,000,000 tons per year commencing in the near future would not overly flood the world market with manganese, nickel or copper. A single operator of such size could, however, have a detrimental effect on the cobalt market, especially if a deposit of high cobalt content were mined and 52% of the world demand for cobalt was produced. This could reduce the current price of cobalt by as much as one third, or from \$2.20 to \$1.49 per pound. Three such mining operations by 1980 would not only flood the world market with cobalt,⁶ but begin an inundation of manganese equal to 9-18% (depending on nodule grade) of the world's manganese production in 1969. The mining of manganese nodules at the rate of three million tons per year would also begin to be felt by the nickel market, especially if high nickel content nodules were

⁶A yield of cobalt equal to 158% of world demand would clearly be disastrous and such would be possible from three million tons of nodules with high cobalt content.









processed. The copper market appears to be safe from detrimental effect.

C. EFFECTS ON 1985 METALS MARKET

A nodule production of over 3,000,000 tons per year probably won't occur before 1980. However, by 1985 the world nodule mining capacity could possibly reach as high as 10,000,000 tons. A comparison of possible mining yields or capacity with projected high and low demands for metal by 1985 is given in Tables IX-XII, Appendix A. Figures 16-19 show the relationships of these mining capacities to low estimates of future demand.

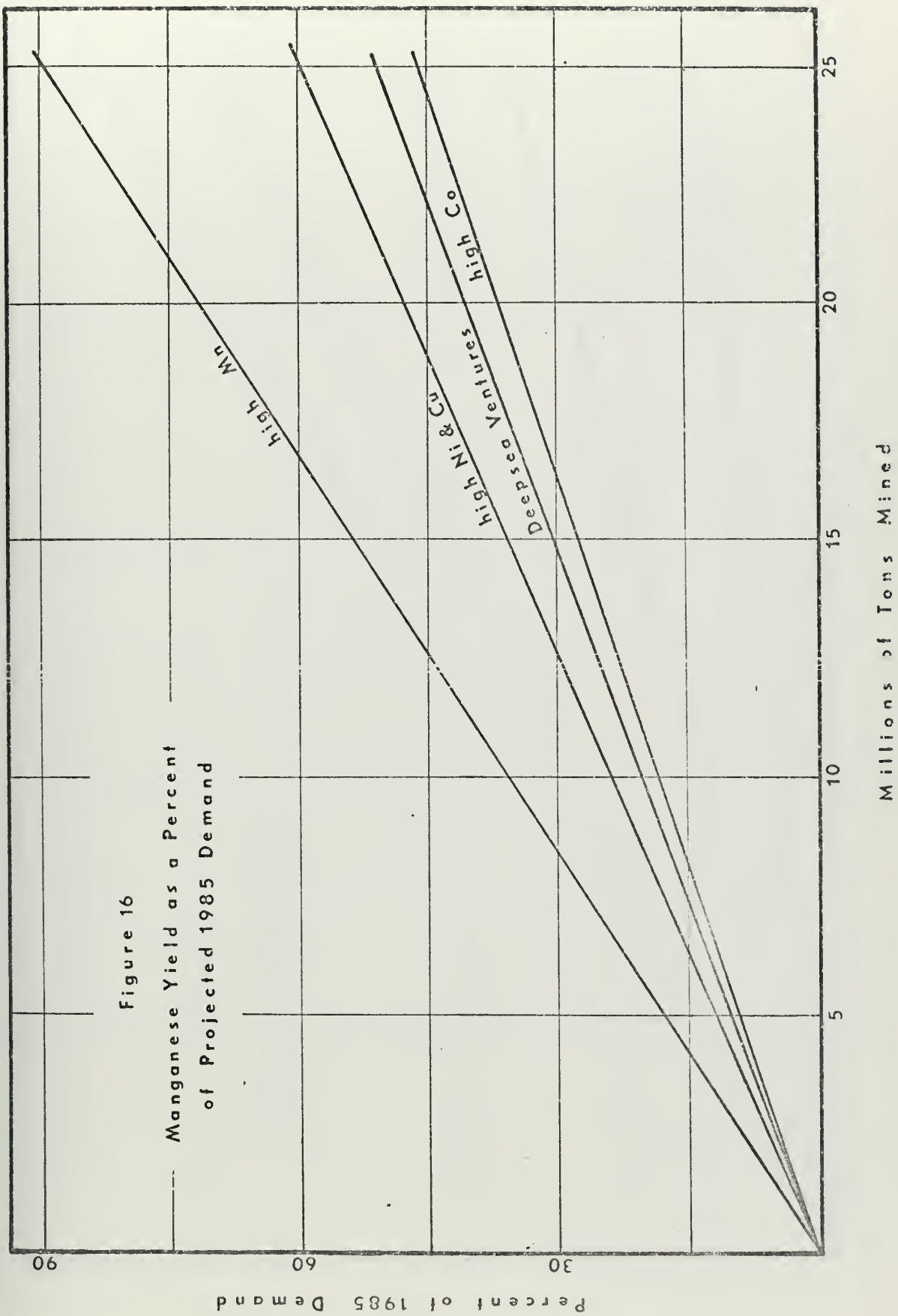
Cobalt clearly will suffer the most. Five million tons of nodules with high cobalt content would meet over 200% of the 1985 demand, and ten million tons would push supply to 458% of the world need, causing the value shown in Table III of cobalt--and the high bearing nodules--to plunge downward. This grade of nodule would then become economically less desirable to exploit, making the high nickel and copper content nodules the optimum type to mine.

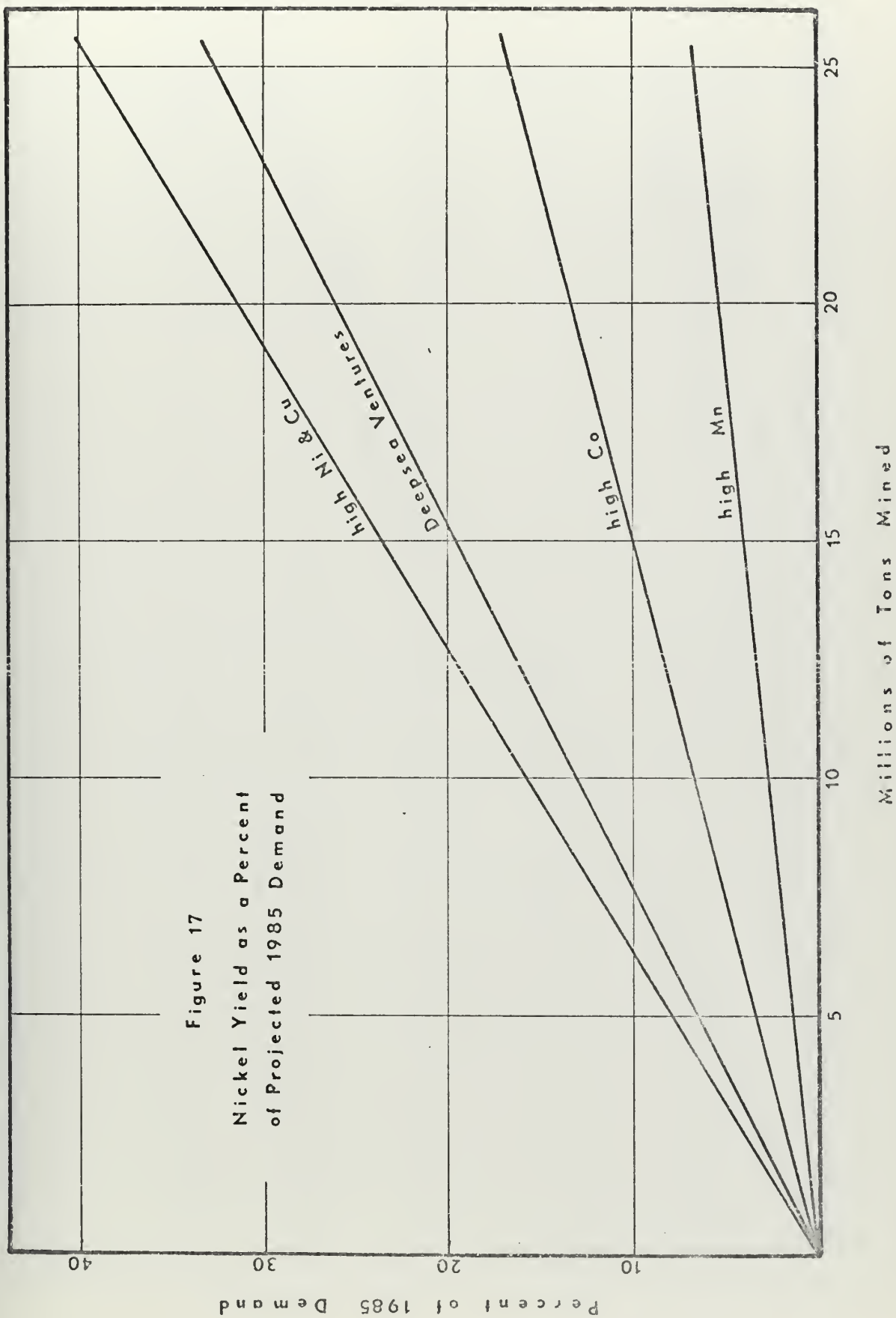
The Deepsea Ventures' mine site nodules may be relatively valuable. Because their manganese, nickel, and cobalt assays are generally less than the high nickel and copper content nodules, increasing production rates would not have as great a depressing effect on the price of those constituent metals.

Of course, if the capacities of the terrestrial mining industry do not increase as fast as world demand, exploitation of manganese nodules will not have as great an effect

Figure 16

Manganese Yield as a Percent
of Projected 1985 Demand





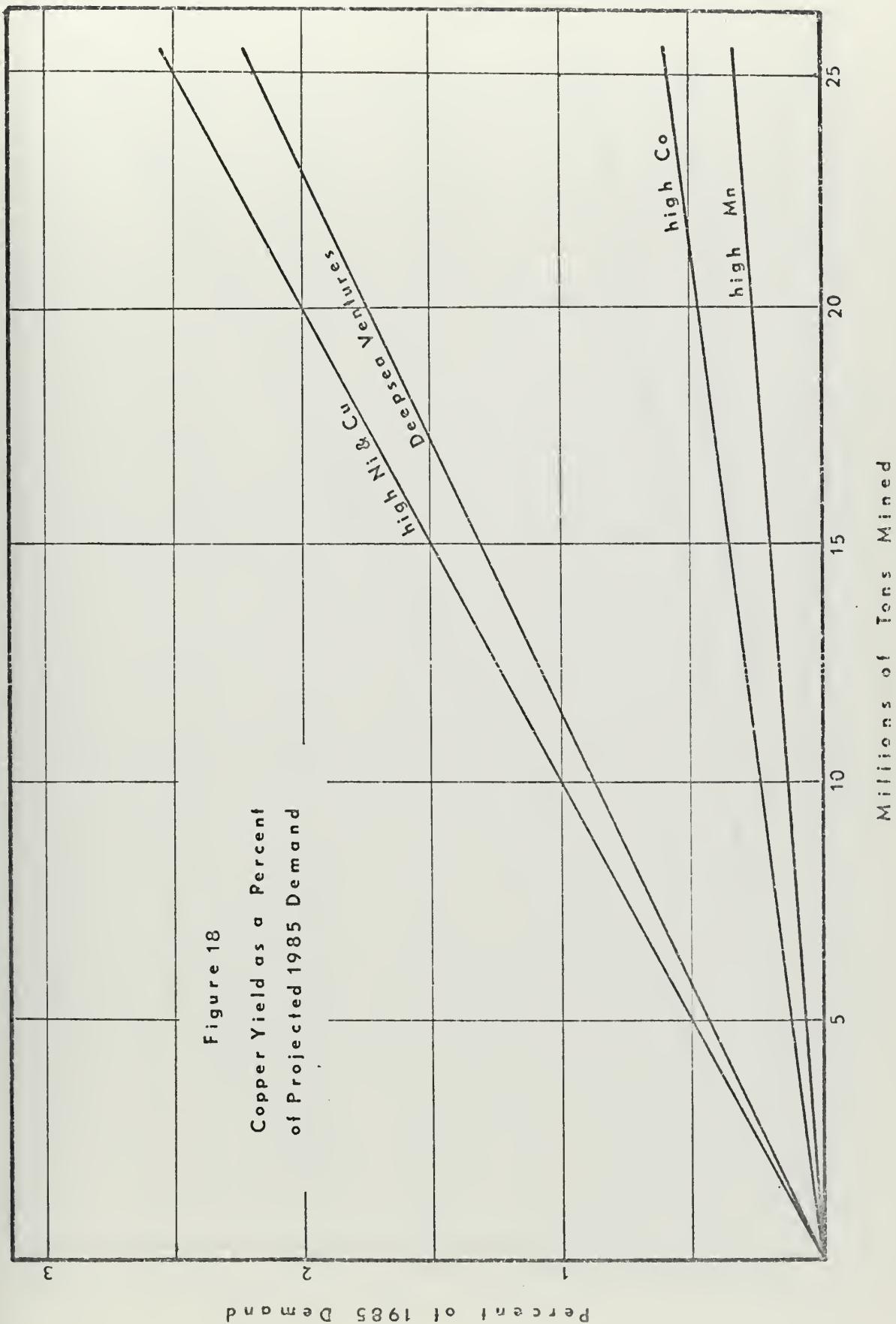
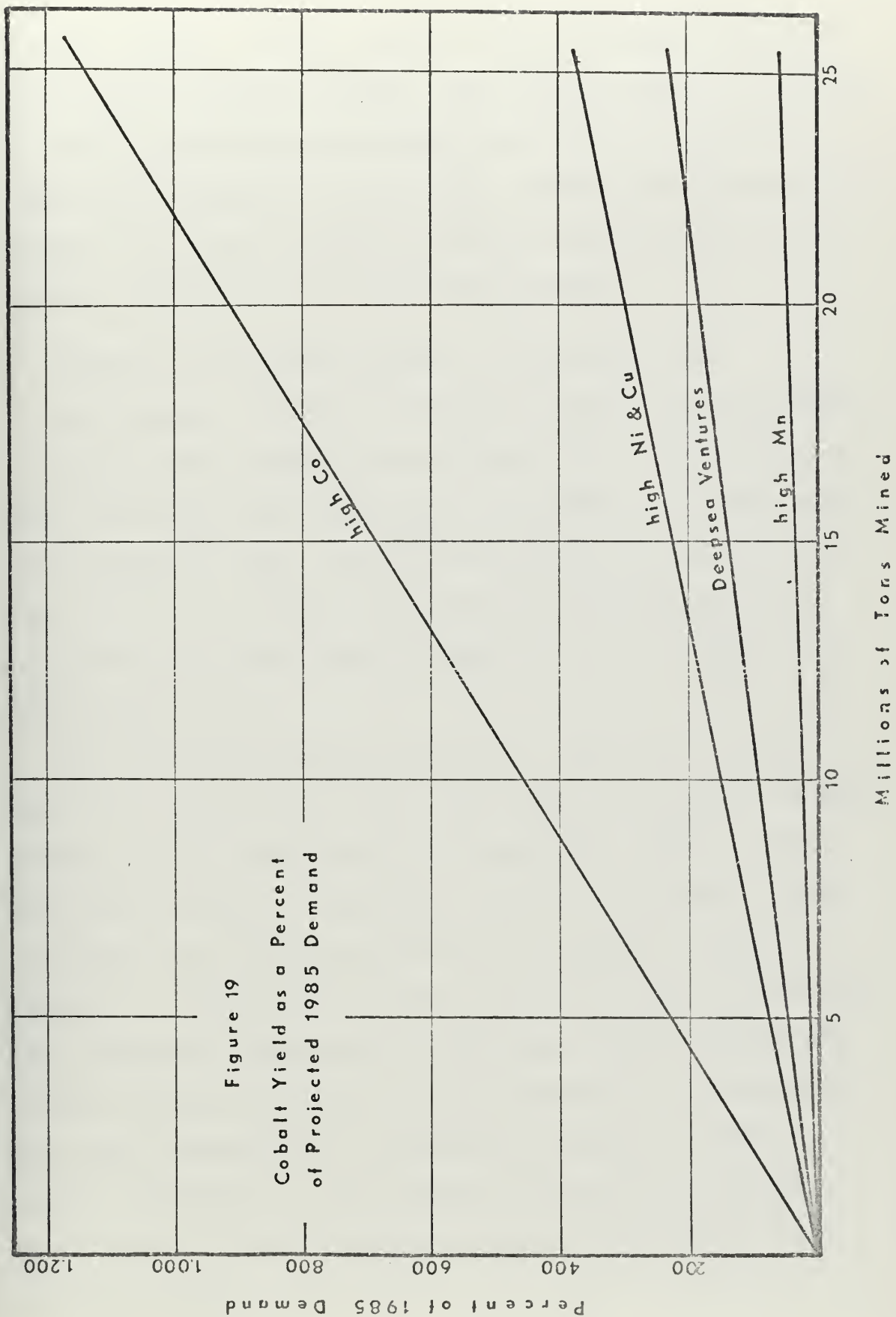


Figure 19
Cobalt Yield as a Percent
of Projected 1985 Demand

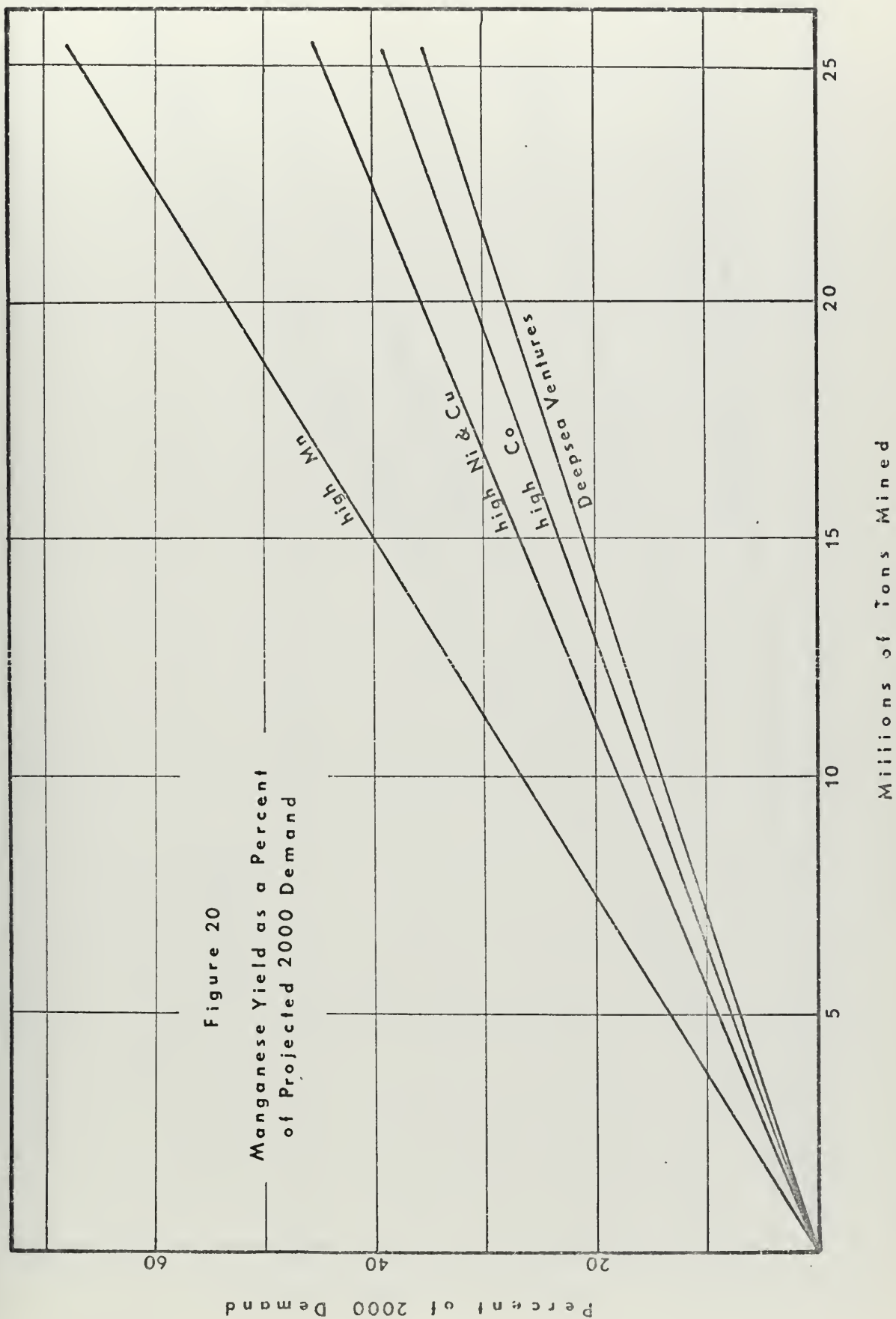


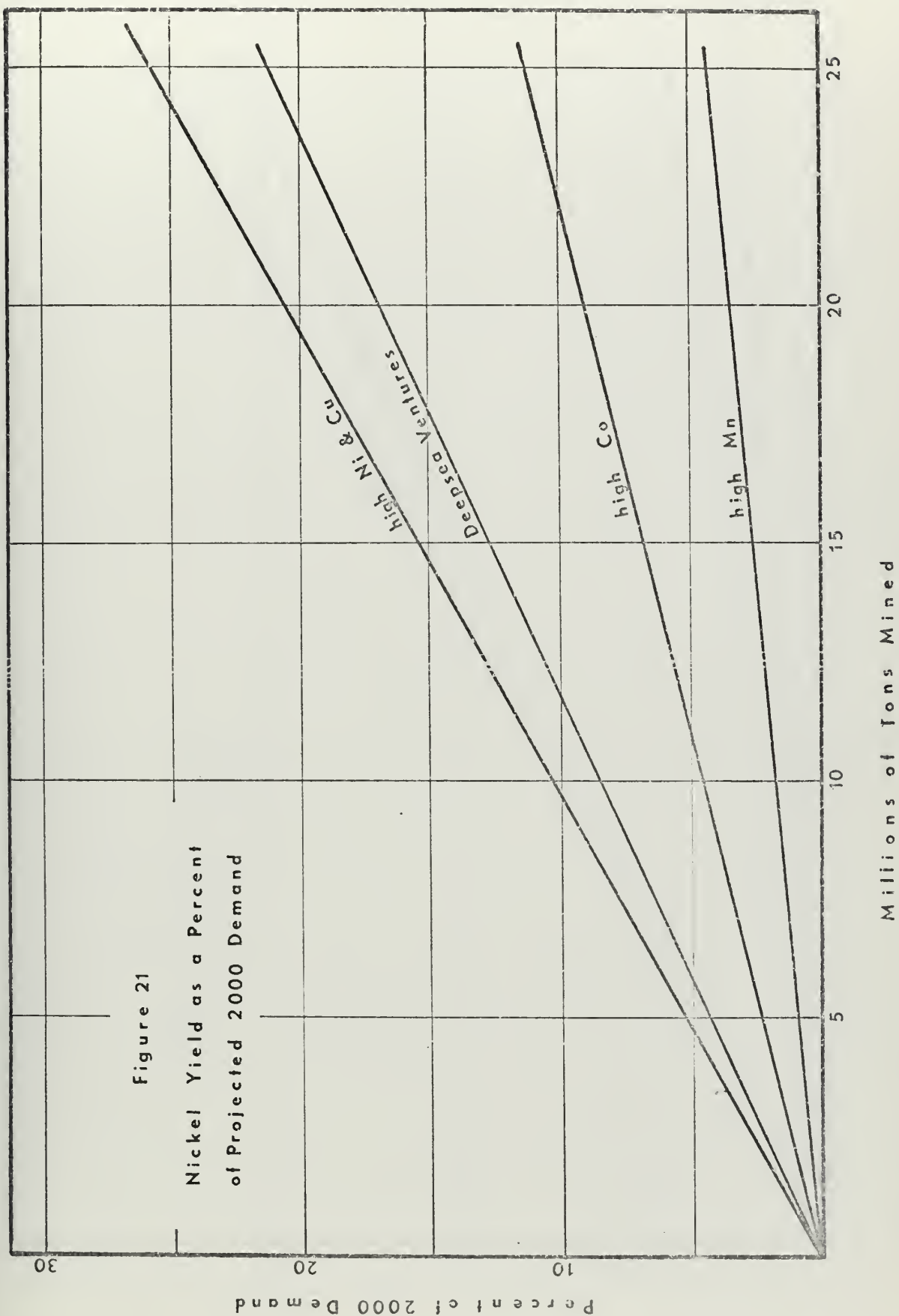
on metal prices. It will serve only to satisfy a portion of the world's greater needs. Such could indeed be the case for all the constituent metals, except cobalt, by 1985. Copper from manganese nodules will certainly fall into this category, as a ten million ton mining capacity could only satisfy a maximum of 1% of the 1985 demand.

D. EFFECTS ON THE METALS MARKET IN THE YEAR 2000

Anticipated increases in demand of about 50% from 1985 to the year 2000 render mining capacities of 15,000,000 tons nearly the same in percentile figures as a 10,000,000 ton capacity in 1985. Mining capacities of twenty million and twenty-five million tons give proportionately higher projections as can be seen in Tables XIII-XVI, Appendix A, and Figures 20-23.

It is evident from the above that the future world market for cobalt will be the only metal industry seriously effected by the exploitation of manganese nodules. The other three metals - manganese, nickel and copper - found in nodules will not have their world markets so much effected, but individual mines, localities or countries may feel stronger consequences. The copper market should not suffer any harm whatsoever, while sectors of the manganese and nickel markets will probably be effected to some extent, depending on the quantity and grade of nodules mined and the future terrestrial mining capacities for these two metals.





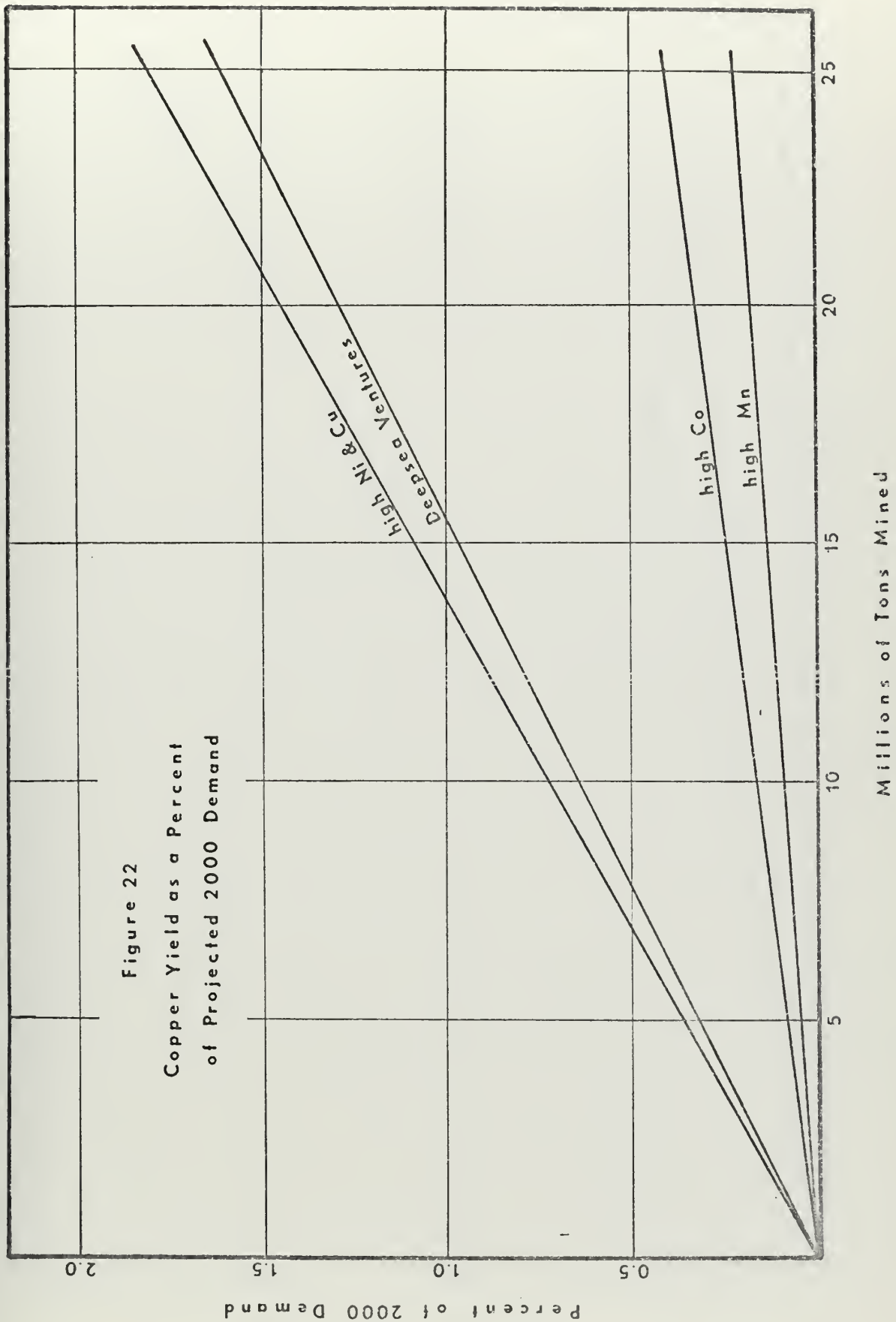
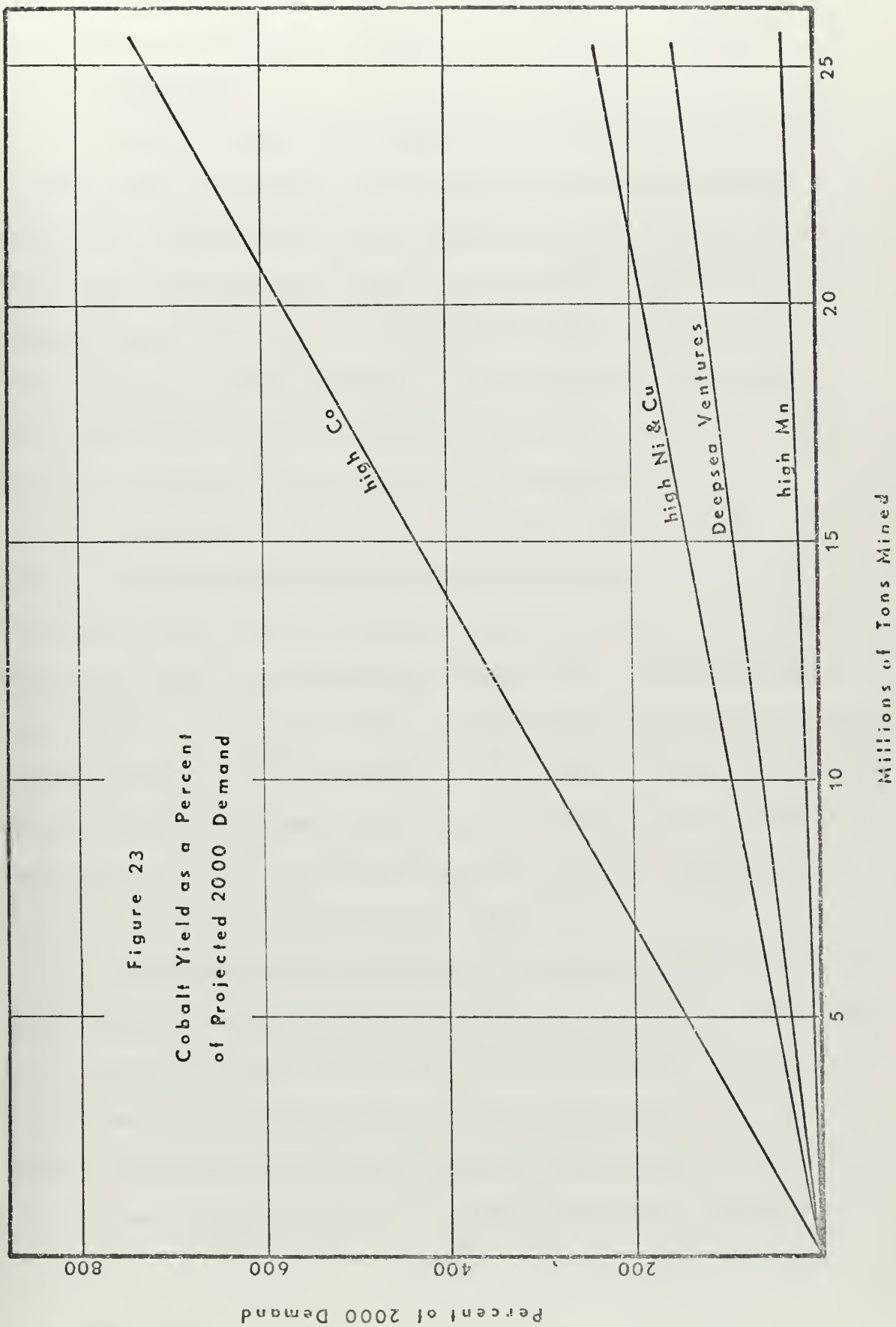


Figure 23
Cobalt Yield as a Percent
of Projected 2000 Demand



E. EFFECT ON DEVELOPING NATIONS WITH MINING INTERESTS

1. Manganese

Table V gives 1969 manganese production statistics for developing countries, the economies of which may be adversely effected by future manganese nodule exploitation. Gross national product (GNP) per capita is given for each country as an indicator of the extent that country is "developing." Other economic or sociological indicators could also be used, but GNP per capita was chosen by this author as the most effective for his purposes.

The economies of Brazil, Indonesia, Gabon, India, and Mainland China would stand to loose the most, in terms of monetary value, from a reduced manganese price.⁷ Of these, Gabon will feel the strongest effect with respect to value per capita. The total value of manganese produced in Gabon in 1969 was 18.5% of its GNP in that year. Other countries with production values amounting to a significant part of their GNP's are: the Congo Republic, 0.67%; Ghana, 0.50%; Indonesia, 0.42%; and Brazil, 0.22%.

If a maximum manganese price reduction of 30% is assumed, the economy of Gabon is the only one which would be severely hurt, based on 1969 statistics. Virtually all the Gabonese manganese is exported, while a large percentage of its mining industry is owned by foreign companies. Compagnie Miniere de l'Ogooue, Gabon's largest manganese producer,

⁷See Table V.

TABLE V

1969 PRODUCTION OF MANGANESE ORE
FROM DEVELOPING COUNTRIES
(Ref. 40)

Country	Production (Short Tons)	% of World Production*	Value	Value Per Capita	GNP PER Capita
Brazil	2,166,260	10.90	\$55,620,000	\$.69	\$310
Indonesia	1,769,000	8.91	45,540,000	.40	95
Gabon	1,502,449	7.58	38,600,000	77.20	417
India	1,100,000	5.54	28,250,000	.05	82
China (Mainland)	1,100,000	5.54	28,250,000	.04	112
Ghana	385,476	1.94	9,890,000	1.18	238
Congo Republic	343,291	1.73	8,820,000	.52	78
Mexico	158,252	0.80	4,070,000	.09	557

* Total 1969 production was 19,864,353 short tons.

has 49% of its ownership held by United States Steel Corporation (Ref. 42). Such extent of foreign ownership perhaps permits one to give less emphasis to the \$77.20 value per capita for manganese shown in Table V.

2. Nickel

Nickel production in 1969 by developing countries is shown at Table VI. The extremely high value per capita for the French territory of New Caledonia may be misleading, because almost the entire nickel industry on New Caledonia is owned by companies in France, Canada and the United States. Nickel production accounted for about 0.21% of the GNP's of both Cuba and Southern Rhodesia. A maximum reduction of 30% in the assumed price for nickel would have only minor effects on the economies of other high nickel producing, developing nations.

3. Copper

Since copper from manganese nodules will constitute a very small percentage of world production, it was concluded earlier that the world copper market would not be severely effected by nodule exploitation. None of the major copper producing, developing countries listed in Table VII should be adversely effected. Even Zambia and Chile, with very large capacities for copper mining, would appear to face no harmful competition. Consequently, the apprehension expressed by the Chilean Ambassador to the United Nations over the effect of manganese nodule

TABLE VI

1969 PRODUCTION OF NICKEL FROM
DEVELOPING COUNTRIES
(Ref. 40)

Country	Production (Short Tons)	% of World Production*	Value	Value Per Capita	GNP Per Capita
New Caledonia	99,731	18.59	\$265,200,000	\$4,080.00	\$
Cuba	38,800	7.32	103,200,000	13.60	658
Southern Rhodesia	8,818	1.54	23,440,000	4.79	230
Indonesia	7,716	1.45	20,500,000	.18	95
Greece	6,614	1.25	17,590,000	2.00	863
Brazil	1,200	0.23	3,750,000	.38	310

* Total 1969 production was 530,495 short tons.

TABLE VII

1969 PRODUCTION OF COPPER FROM
DEVELOPING COUNTRIES
(Ref. 40)

Country	Production (Short Tons)	% of World Production*	Value	Value Per Capita	GNP Per Capita
Zambia	824,711	12.48	\$857,200,000	\$209.00	\$ 326
Chile	768,716	11.62	800,000,000	87.00	614
Congo Republic	399,274	6.04	415,000,000	24.40	78
Peru	227,235	3.44	236,200,000	18.46	336
Philippines	144,873	2.19	150,600,000	4.19	203
China (Mainland)	110,000	1.66	114,300,000	.18	112
Mexico	72,936	1.10	75,800,000	1.60	557
Bulgaria	42,000	0.64	43,700,000	5.12	1,083
South-West Africa	30,450	0.46	31,700,000		
Southern Rhodesia	26,450	0.40	27,500,000	5.61	230
Cyprus	21,968	0.33	22,800,000	38.00	704
Uganda	21,825	0.33	22,700,000	2.79	122

* Total 1969 production was 6,612,276 short tons.

exploitation on his country's recently nationalized industry is unwarranted (Ref. 43).

4. Cobalt

The world market for cobalt, which should suffer the greatest reduction in price as a result of manganese nodule exploitation, is especially significant for a number of developing nations shown in Table VIII. The Congo Republic, Cuba, Morocco and Zambia would feel the pinch of cobalt price reductions on their economies. The 1969 cobalt production values as a percent of GNP for these countries was: Congo Republic, 3.64%; Zambia, 0.50%; Morocco, 0.25%; and Cuba, 0.15%. With a drastic drop in the price of cobalt, a certainty if production were several hundred percent greater than world demand, the cobalt capacities of these nations would have little value.

TABLE VIII

1969 PRODUCTION OF COBALT FROM
DEVELOPING COUNTRIES
(Ref. 40)

Country	Production (Short Tons)	% of World Production*	Value	Value Per Capita	GNP Per Capita
Congo Republic	11,000	49.35	\$48,400,000	\$2.84	\$ 78
Cuba	1,700	7.63	7,500,000	.99	658
Morocco	1,700	7.63	7,500,000	.51	204
Zambia	1,650	7.40	7,300,000	1.77	326

* Total 1969 production was 22,296 short tons.

VI. CONCLUSION

In a policy statement on the seabed, President Nixon declared in his U.S. Foreign Policy for the 1970's:

"We are seeking a system which fully protects the interests of the less-developed countries in the ocean resources, as well as the interests of those nations which now possess the technological capacity to exploit them. Such an arrangement is both fair and practical. For these resources are a common heritage of mankind, and their benefits should be shared by all. And the world is unlikely to give its sanction to arrangements which do not ensure a wide sharing of these benefits. The mineral royalties involved will eventually be very large. Earmarking them for international purposes - particularly the development of poorer nations - could be a tremendous step forward toward a solution to one of the world's most grievous problems" (Ref. 44).

If the interests of less-developed nations are to be protected, one would expect that the first call upon collected royalties from exploitation of the seabed would be for compensation to those developing countries whose economies are detrimentally effected by the competition. Obviously, such just disbursements will shrink the monies available for economic assistance to all developing countries and other international purposes.

From facts presently known, it can be shown that manganese nodule exploitation alone will not produce the vast wealth necessary to provide affluence for all of mankind. Based on 1971 metal prices and the Deepsea Ventures' nodule grade shown in Table III, anticipated gross values of future nodule exploitation are given below in Table IX:

TABLE IX
PROJECTED WORTH OF MANGANESE NODULE EXPLOITATION

Year	Mining Capacity	Gross Value
1976	1,000,000 tons	\$ 67,430,000
1985	10,000,000	674,300,000
2000	25,000,000	1,685,750,000

A royalty amounting to 10% of these gross values would provide \$6,743,000 in 1976; \$67,430,000 in 1985; and \$168,575,000 in the year 2000 for the benefit of the world community, including needs of developing countries. Such sums are not monumental when compared with current expenditures of the United Nations system, which are in the neighborhood of \$1 billion annually. However, they would be marginally significant with respect to 1970 authorized expenditures of the United Nations Educational, Scientific and Cultural Organization (UNESCO) at \$44.3 million or the World Health Organization (WHO) at \$75.8 million (Ref. 45).

By the year 2000, other deep ocean resources will have joined manganese nodules as new world mineral reserves. Nevertheless, the future exploitation of sedimentary materials such as calcareous and diatom oozes or red clay deposits is in doubt. Even if the economic structure of the world minerals market changes to allow profitable gathering of these materials, their low value could not

likely provide large royalties. With extensive exploration and research, Red Sea metaliferrous muds, however, should prove profitable, perhaps by the year 2000. But, royalties to be gained from these minerals would be insignificant compared to the needs of developing countries, because 10% of the total value of sediments in the top ten meters of these deposits will likely amount to only \$250 million.⁸

Deep seabed petroleum will eventually prove to be the most lucrative deep ocean resource of all from the viewpoint of the international community. Semi-enclosed seas with potential oil bearing crustal structures, continental rises and continental slopes have a combined sediment volume far exceeding that of the continental shelves. Therefore, it is reasonable to assume that petroleum production from the deep seabed at some future date will at least equal current offshore production. A portion of this wealth will surely be realized by the year 2000.

An international regime for the regulation of deep ocean mineral resources should be established promptly and its first subject is certain to be the exploitation of manganese nodules and the equitable allocation of royalties. It will also have to cope with the detrimental effects of exploitation of these minerals on national economies. Thus, when additional resources from the ocean deep become available, there will already be in operation a practical scheme for

⁸See Table II.

sharing the wealth of the oceans. If the community of nations at the 1973 conference on the law of the sea act wisely, the seabeds and the resources they hold will benefit all of mankind rather than become yet another source of conflict.

APPENDIX A

METAL YIELD COMPARISON TABLES

TABLE A-I

METAL YIELD FOR HIGH MANGANESE CONTENT NODULES
(Tons-Per-Year)

Mining Capacity	Manganese	Nickel	Copper	Cobalt
1,000,000	488,000	2,550	1,370	540
2,000,000	976,000	5,100	2,740	1,080
3,000,000	1,464,000	7,650	4,110	1,620
4,000,000	1,952,000	10,200	5,480	2,160
5,000,000	2,440,000	12,750	6,850	2,700
6,000,000	2,928,000	15,300	8,220	3,240
7,000,000	3,416,000	17,850	9,590	3,870
8,000,000	3,904,000	20,400	10,960	4,320
9,000,000	4,392,000	22,950	12,330	4,860
10,000,000	4,880,000	25,500	13,700	5,400
15,000,000	7,320,000	38,250	20,550	8,100
20,000,000	9,760,000	51,000	27,400	10,800
25,000,000	12,200,000	63,750	34,250	13,500

TABLE A-II

METAL YIELD FROM HIGH NICKEL AND COPPER CONTENT NODULES
(Tons-Per-Year)

Mining Capacity	Manganese	Nickel	Copper	Cobalt
1,000,000	326,300	14,900	11,080	3,820
2,000,000	652,600	29,800	22,160	7,640
3,000,000	978,900	44,700	33,240	11,460
4,000,000	1,305,200	59,600	44,320	15,280
5,000,000	1,631,500	74,500	55,400	19,100
6,000,000	1,957,800	89,400	66,480	22,920
7,000,000	2,283,100	104,300	77,560	26,740
8,000,000	2,610,400	119,200	88,640	30,560
9,000,000	2,936,700	134,100	99,720	34,380
10,000,000	3,263,000	149,000	110,800	38,200
15,000,000	4,894,500	223,500	166,200	57,300
20,000,000	6,526,000	298,000	221,600	76,400
25,000,000	8,157,500	372,500	277,000	95,500

TABLE A-III
METAL YIELD FROM HIGH COBALT CONTENT NODULES
(Tons-Per-Year)

Mining Capacity	Manganese	Nickel	Copper	Cobalt
1,000,000	279,200	6,470	2,580	11,760
2,000,000	558,400	12,940	5,160	23,520
3,000,000	837,600	19,410	7,740	35,280
4,000,000	1,116,800	25,880	10,320	47,040
5,000,000	1,396,000	32,350	12,900	58,800
6,000,000	1,675,200	38,820	15,480	70,560
7,000,000	1,954,400	45,290	18,060	82,320
8,000,000	2,233,600	51,760	20,640	94,080
9,000,000	2,512,800	58,230	23,220	105,840
10,000,000	2,792,000	64,700	25,800	117,600
15,000,000	4,188,000	94,050	38,700	186,400
20,000,000	5,584,000	129,400	51,600	235,200
25,000,000	6,980,000	161,750	64,500	294,000

TABLE A-IV

METAL YIELD FROM DEEPSEA VENTURES' CANDIDATE MINESITE
(Tons-Per-Year)

Mining Capacity	Manganese	Nickel	Copper	Cobalt
1,000,000	254,500	12,340	9,800	2,350
2,000,000	509,000	24,680	19,600	4,710
3,000,000	764,000	37,020	29,400	7,060
4,000,000	1,019,000	49,360	39,200	9,400
5,000,000	1,273,000	61,700	49,000	11,750
6,000,000	1,528,000	74,040	58,800	14,110
7,000,000	1,783,000	86,380	68,600	16,470
8,000,000	2,038,000	98,720	78,400	18,820
9,000,000	2,292,000	111,060	88,200	21,170
10,000,000	2,545,000	123,400	98,000	23,520
15,000,000	3,819,000	185,200	147,000	35,280
20,000,000	5,090,000	246,800	196,000	47,050
25,000,000	6,365,000	308,500	245,000	58,800

TABLE A-V

METAL YIELD FROM HIGH MANGANESE CONTENT
NODULES AS A PERCENT OF 1969 PRODUCTION

Mining Capacity	Manganese	Nickel	Copper	Cobalt
1,000,000	6.0	0.5	0.02	2.4
2,000,000	12.0	1.0	0.04	4.8
3,000,000	18.0	1.4	0.06	7.3
4,000,000	24.0	1.9	0.08	9.7
5,000,000	29.9	2.4	0.10	12.1
6,000,000	35.9	2.9	0.13	14.5
7,000,000	41.8	3.4	0.15	17.3
8,000,000	47.8	3.8	0.17	19.4
9,000,000	53.8	4.3	0.19	21.8
10,000,000	59.8	4.8	0.21	24.2
15,000,000	89.8	7.2	0.31	36.3
20,000,000	119.7	9.6	0.41	48.4
25,000,000	149.6	12.0	0.52	60.6

TABLE A-VI
METAL YIELD FROM HIGH NICKEL AND COPPER CONTENT
NODULES AS A PERCENT OF 1969 PRODUCTION

Mining Capacity	Manganese	Nickel	Copper	Cobalt
1,000,000	4.0	2.8	0.2	17.1
2,000,000	8.0	5.6	0.3	34.2
3,000,000	12.0	8.4	0.5	51.4
4,000,000	16.0	11.2	0.7	68.5
5,000,000	20.0	14.0	0.8	85.7
6,000,000	24.0	16.8	1.0	102.8
7,000,000	28.0	19.7	1.2	119.9
8,000,000	32.0	22.5	1.3	137.0
9,000,000	36.0	25.3	1.5	154.1
10,000,000	40.0	28.1	1.7	171.2
15,000,000	60.0	42.1	2.5	256.9
20,000,000	80.0	56.2	3.3	342.5
25,000,000	100.0	70.2	4.2	428.0

TABLE A-VII
METAL YIELD FROM HIGH COBALT CONTENT NODULES
AS A PERCENT OF 1969 PRODUCTION

Mining Capacity	Manganese	Nickel	Copper	Cobalt
1,000,000	3.4	1.2	0.03	52.7
2,000,000	6.8	2.4	0.08	105.4
3,000,000	10.3	3.7	0.12	158.1
4,000,000	13.7	4.9	0.16	211.0
5,000,000	17.1	6.1	0.20	263.6
6,000,000	20.5	7.3	0.23	316.3
7,000,000	24.0	8.5	0.27	369.2
8,000,000	27.4	9.8	0.31	421.8
9,000,000	30.8	11.0	0.34	475.0
10,000,000	34.2	12.2	0.39	527.3
15,000,000	51.4	17.7	0.59	791.4
20,000,000	68.5	24.4	0.78	1053.8
25,000,000	85.6	30.1	0.98	1318.5

TABLE A-VIII

METAL YIELD FROM DEEPSEA VENTURES' MINE SITE
AS A PERCENT OF 1969 PRODUCTION

Mining Capacity	Manganese	Nickel	Copper	Cobalt
1,000,000	3.1	2.3	0.1	10.5
2,000,000	6.2	4.6	0.3	21.1
3,000,000	9.4	6.9	0.4	31.6
4,000,000	12.5	9.3	0.6	42.2
5,000,000	15.6	11.5	0.7	52.7
6,000,000	18.7	13.9	0.9	63.3
7,000,000	21.8	16.1	1.0	73.9
8,000,000	24.9	18.5	1.2	84.4
9,000,000	28.1	20.9	1.3	94.9
10,000,000	31.2	23.2	1.5	105.3
15,000,000	46.8	34.9	2.2	158.1
20,000,000	62.4	46.6	3.0	211.2
25,000,000	77.9	58.8	3.7	263.7

TABLE A-IX

METAL YIELD FROM HIGH MANGANESE CONTENT NODULES
AS A PERCENT OF 1985 PROJECTED DEMANDS

Mining Capacity	Manganese		Nickel		Copper		Cobalt	
	Low	High	Low	High	Low	High	Low	High
1,000,000	3.6	2.7	0.3	0.3	0.01	0.01	2.1	1.9
2,000,000	7.1	5.4	0.5	0.5	0.02	0.02	4.2	3.8
3,000,000	10.6	8.2	0.8	0.8	0.04	0.03	0.3	5.7
4,000,000	14.2	10.9	1.1	1.0	0.05	0.04	8.4	7.6
5,000,000	17.8	13.6	1.3	1.3	0.06	0.05	10.5	9.6
6,000,000	21.4	16.3	1.6	1.5	0.07	0.06	12.6	11.5
7,000,000	24.9	19.0	1.9	1.8	0.09	0.07	15.1	13.7
8,000,000	28.5	21.7	2.1	2.0	0.10	0.08	16.8	15.3
9,000,000	32.0	24.3	2.4	2.3	0.11	0.09	19.0	17.2
10,000,000	35.6	27.2	2.7	2.5	0.12	0.10	21.1	19.1
15,000,000	53.4	40.7	4.0	3.8	0.18	0.15	31.6	28.6
20,000,000	71.2	54.4	5.3	5.0	0.24	0.20	42.1	38.6
25,000,000	89.0	68.0	6.6	6.3	0.31	0.25	52.7	47.8

TABLE A-X

METAL YIELD FROM HIGH NICKEL AND COPPER CONTENT
NODULES AS A PERCENT OF 1985 PROJECTED DEMAND

Mining Capacity	Manganese		Nickel		Copper		Cobalt	
	Low	High	Low	High	Low	High	Low	High
1,000,000	2.4	1.8	1.6	1.5	0.1	0.1	14.9	13.5
2,000,000	4.8	3.6	3.1	2.9	0.2	0.2	29.8	27.0
3,000,000	7.1	5.4	4.7	4.4	0.3	0.2	44.6	40.5
4,000,000	9.5	7.3	6.2	5.9	0.4	0.3	59.6	54.1
5,000,000	11.8	9.1	7.8	7.3	0.5	0.4	74.5	67.7
6,000,000	14.3	10.9	9.3	8.8	0.6	0.5	89.4	81.1
7,000,000	16.7	12.7	10.9	10.3	0.7	0.6	104.1	94.7
8,000,000	19.1	14.5	12.4	11.7	0.8	0.7	119.0	108.1
9,000,000	21.4	16.3	14.0	13.2	0.9	0.7	133.9	121.5
10,000,000	24.8	18.2	15.5	14.6	1.0	0.8	148.9	135.1
15,000,000	35.7	27.3	23.3	21.9	1.5	1.2	223.3	202.5
20,000,000	47.6	36.4	31.1	29.3	2.0	1.6	297.9	270.1
25,000,000	59.5	45.5	38.8	36.6	2.5	2.1	372.0	338.0

TABLE A-XI

METAL YIELD FROM HIGH COBALT CONTENT NODULES
AS A PERCENT OF 1985 PROJECTED DEMAND

Mining Capacity	Manganese		Nickel		Copper		Cobalt	
	Low	High	Low	High	Low	High	Low	High
1,000,000	2.0	1.6	0.7	0.6	0.02	0.02	45.8	41.6
2,000,000	4.1	3.1	1.3	1.3	0.05	0.04	91.7	83.2
3,000,000	6.1	4.7	2.0	1.9	0.07	0.06	137.6	124.9
4,000,000	8.1	6.2	2.7	2.5	0.09	0.08	188.3	166.5
5,000,000	10.2	7.8	3.4	3.1	0.12	0.10	229.2	208.0
6,000,000	12.2	9.3	4.0	3.8	0.14	0.11	275.0	249.8
7,000,000	14.3	10.9	4.7	4.5	0.16	0.13	321.0	291.4
8,000,000	16.3	12.4	5.4	5.1	0.18	0.15	366.7	333.0
9,000,000	18.3	14.0	6.1	5.7	0.21	0.17	412.2	374.4
10,000,000	20.4	15.5	6.7	6.4	0.23	0.19	458.1	416.0
15,000,000	30.6	23.4	9.8	9.3	0.35	0.29	727.0	659.0
20,000,000	40.7	31.1	13.5	12.7	0.46	0.38	917.2	832.2
25,000,000	50.9	38.9	16.9	15.9	0.58	0.48	1145.8	1040.0

TABLE A-XII

METAL YIELD FROM DEEPSEA VENTURES' MINE SITE
AS A PERCENT OF 1985 PROJECTED DEMANDS

Mining Capacity	Manganese		Nickel		Copper		Cobalt	
	Low	High	Low	High	Low	High	Low	High
1,000,000	1.9	1.4	1.3	1.2	0.1	0.1	9.2	8.3
2,000,000	3.7	2.8	2.6	2.4	0.2	0.1	18.3	16.7
3,000,000	5.6	4.2	3.9	3.6	0.3	0.2	27.5	25.0
4,000,000	7.4	5.7	5.1	4.8	0.3	0.3	36.6	33.3
5,000,000	9.3	7.1	6.4	6.0	0.4	0.4	45.8	41.6
6,000,000	11.1	8.5	7.7	7.3	0.5	0.4	55.0	50.0
7,000,000	13.0	9.9	9.0	8.5	0.6	0.5	64.2	58.3
8,000,000	14.9	11.3	10.3	9.7	0.7	0.6	73.4	66.6
9,000,000	16.7	12.8	11.6	10.9	0.8	0.7	82.4	74.9
10,000,000	18.6	14.2	12.9	12.1	0.9	0.7	91.6	83.2
15,000,000	27.8	21.4	19.3	18.2	1.3	1.0	137.6	124.9
20,000,000	37.1	28.4	25.7	24.2	1.8	1.5	183.4	166.6
25,000,000	46.5	35.5	32.4	30.3	2.2	1.8	229.2	208.0

TABLE A-XIII

METAL YIELD FROM HIGH MANGANESE CONTENT NODULES
AS A PERCENT OF 2000 PROJECTED DEMAND

Mining Capacity	Manganese		Nickel		Copper		Cobalt	
	Low	High	Low	High	Low	High	Low	High
1,000,000	2.7	2.0	0.2	0.2	0.01	0.01	1.3	1.1
2,000,000	5.3	4.1	0.4	0.3	0.02	0.01	2.7	2.2
3,000,000	8.0	6.1	0.5	0.5	0.03	0.02	4.0	3.3
4,000,000	10.7	8.2	0.7	0.6	0.03	0.03	5.3	4.4
5,000,000	13.4	10.2	0.9	0.8	0.04	0.03	6.7	5.5
6,000,000	16.0	12.2	1.1	0.9	0.05	0.04	8.0	6.6
7,000,000	18.7	14.3	1.2	1.1	0.06	0.05	9.5	7.9
8,000,000	21.4	16.3	1.4	1.2	0.07	0.05	10.6	8.9
9,000,000	24.0	18.4	1.6	1.4	0.08	0.06	12.0	9.9
10,000,000	26.7	20.4	1.7	1.5	0.09	0.07	13.3	11.1
15,000,000	40.1	30.6	2.6	2.3	0.13	0.10	20.0	16.6
20,000,000	53.5	40.8	3.5	3.1	0.17	0.13	26.9	22.1
25,000,000	66.9	51.0	4.4	3.8	0.22	0.17	33.3	27.6

TABLE A-XIV

METAL YIELD FROM HIGH NICKEL AND COPPER CONTENT NODULES
AS A PERCENT OF 2000 PROJECTED DEMAND

Mining Capacity	Manganese		Nickel		Copper		Cobalt	
	Low	High	Low	High	Low	High	Low	High
1,000,000	1.8	1.4	1.0	0.9	0.1	0.05	9.4	7.8
2,000,000	3.6	2.7	2.0	1.8	0.1	0.11	18.8	15.6
3,000,000	5.4	4.1	3.1	2.7	0.2	0.16	28.2	23.4
4,000,000	7.2	5.5	4.1	3.6	0.3	0.22	37.6	31.3
5,000,000	8.9	6.8	5.1	4.5	0.4	0.27	47.0	39.2
6,000,000	10.7	8.2	6.1	5.4	0.4	0.32	56.4	46.9
7,000,000	12.5	9.6	7.1	6.3	0.5	0.38	65.8	54.8
8,000,000	14.3	10.9	8.1	7.2	0.6	0.42	75.2	62.5
9,000,000	16.1	12.3	9.2	8.1	0.6	0.48	84.6	70.4
10,000,000	17.9	14.7	10.2	9.0	0.7	0.54	94.0	78.2
15,000,000	26.8	20.4	15.3	13.4	1.1	0.81	141.0	117.1
20,000,000	35.7	27.3	19.7	18.7	1.4	1.07	187.9	156.3
25,000,000	44.7	34.1	25.4	22.4	1.8	1.34	234.9	195.4

TABLE A-XV

METAL YIELD FROM HIGH COBALT CONTENT NODULES
AS A PERCENT OF PROJECTED 2000 DEMAND

Mining Capacity	Manganese		Nickel		Copper		Cobalt	
	Low	High	Low	High	Low	High	Low	High
1,000,000	1.5	1.2	0.4	0.4	0.02	0.01	28.9	24.1
2,000,000	3.1	2.3	0.9	0.8	0.03	0.03	57.8	48.1
3,000,000	4.6	3.5	1.3	1.2	0.05	0.04	86.8	72.2
4,000,000	6.1	4.7	1.8	1.6	0.07	0.05	115.8	96.4
5,000,000	7.6	5.8	2.2	1.9	0.08	0.06	144.7	118.7
6,000,000	9.2	7.0	2.7	2.3	0.10	0.08	173.4	144.3
7,000,000	10.7	8.2	3.1	2.7	0.12	0.09	202.2	168.5
8,000,000	12.2	9.4	3.5	3.1	0.13	0.10	231.4	192.5
9,000,000	13.8	10.5	4.0	3.5	0.15	0.11	260.1	216.4
10,000,000	15.3	11.7	4.4	3.9	0.16	0.13	288.4	240.5
15,000,000	23.0	17.5	6.4	5.7	0.25	0.19	458.2	382.0
20,000,000	30.6	23.4	8.8	7.8	0.33	0.25	578.2	481.4
25,000,000	38.4	29.2	11.0	9.7	0.41	0.31	723.8	602.0

TABLE A-XVI

METAL YIELD FROM DEEPSEA VENTURES' MINE SITE
AS A PERCENT OF 2000 PROJECTED DEMAND

Mining Capacity	Manganese		Nickel		Copper		Cobalt	
	Low	High	Low	High	Low	High	Low	High
1,000,000	1.4	1.1	0.8	0.7	0.1	0.05	5.7	4.8
2,000,000	2.8	2.1	1.7	1.5	0.1	0.10	11.6	9.6
3,000,000	4.2	3.2	2.5	2.2	0.2	0.14	17.4	14.4
4,000,000	5.6	4.3	3.4	3.0	0.3	0.19	23.2	19.2
5,000,000	7.0	5.3	4.2	3.7	0.3	0.24	29.0	24.1
6,000,000	8.4	6.4	5.1	4.5	0.4	0.29	34.8	28.9
7,000,000	9.8	7.5	5.9	5.2	0.4	0.33	40.6	33.7
8,000,000	11.1	8.5	6.7	5.9	0.5	0.38	46.4	38.6
9,000,000	12.5	9.6	7.6	6.7	0.5	0.43	52.2	43.3
10,000,000	13.9	10.7	8.4	7.4	0.6	0.48	57.9	48.1
15,000,000	20.9	16.0	12.7	11.1	0.9	0.71	87.0	72.2
20,000,000	27.8	21.3	16.9	14.8	1.3	0.95	116.1	96.4
25,000,000	34.9	26.6	21.1	18.5	1.6	1.19	145.0	120.2

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)

Naval Postgraduate School
Monterey, California 93940

2a. REPORT SECURITY CLASSIFICATION

Unclassified

2b. GROUP

3 REPORT TITLE

ECONOMIC EFFECTS OF DEEP OCEAN MINERALS EXPLOITATION

4 DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; September 1971

5. AUTHOR(S) (First name, middle initial, last name)

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6 REPORT DATE

September 1971

7a. TOTAL NO. OF PAGES

93

7b. NO. OF REFS

45

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10 DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

Naval Postgraduate School
Monterey, California 93940

13. ABSTRACT

Any international regime established to regulate the exploitation of deep ocean mineral resources will be shaped greatly by the effect this exploitation may have on the world economy. Many deep ocean mineral deposits are potentially available, but manganese nodules will probably be the first to be exploited.

This study of the economics of manganese nodules concludes that realistic production rates will severely effect the world's market price of cobalt; have significant effect on manganese and nickel prices; and cause little or no changes in the world copper market. It also shows that the royalties to be gained from an international tax or leasing system for exploitation of these nodules will not be great enough to augment significantly the economic assistance to developing nations. However, the exploitation of manganese nodules could be detrimental to the economies of specific developing countries with manganese, nickel or cobalt mining industries.

KEY WORDS

DEEP OCEAN MINERALS

MANGANESE NODULES

MINERAL ROYALTIES

LINK A

LINK B

LINK C

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